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The magic ingredient

History tells us that private companies can turn the racing world around

Sat in the paddock at the opening round of the FIA World Endurance Championship in Qatar was a rather pretty Ferrari 500 Maranello, the car that dominated GT racing around the turn of the century. The car in the paddock carried the colours of the Veloqx Motorsport team.

Looking around it with interest was the broadcaster, 2014 WEC champion and Ferrari 550 Le Mans racer, Anthony Davidson. He wondered aloud whether the car had been fitted with a different steering wheel, as there were almost no buttons on it. Drinks and radio was pretty much it, but he quickly remembered that was all these cars were fitted with in period. Elsewhere in the cockpit, there was a push-pull sequential gear lever that looked pretty weighty.

The car offered us all a quick trip down memory lane. It reminded me of a time when GT racing was returning to its glory days, culminating in the epic duels between Ferrari and Corvette, the mighty Maserati MC12 GT1 and the glorious-sounding Lamborghini Murciélagos. How did it get there, after almost all the competing manufacturers pulled out after the 1998 season?

Brand factor

Put simply, series organiser, Stéphane Ratel, realised he needed the brands, but the brands themselves were not willing to spend the money it took to race in his series. Critically, he needed Ferrari, and the Italian manufacturer had already cancelled its F50 programme. So, he laid the groundwork to bring the 550 Maranello to track without Ferrari.

The first step he took was one remarkably similar to that now on the table for the FIA World Rally Championship, as detailed elsewhere in this issue: open the door to tuners.

This was not a popular move. Manufacturers wanted to retain control of their cars, and the last thing they wanted was for someone else to create a race version of their own product, but Ratel pushed it through with the introduction of 'Technical Passports'. That gave him the chance to have a Ferrari 550 built by Italian company, ItalTecnica, called the 550 'Millennio'. It was not the most successful car ever created, and only showed up at a handful of races.

Frédéric Dor took the car to Prodrive and asked the company to rescue it. Prodrive said it could not, and would need to start again. George Howard-Chappell was tasked with the plan, so called up his friend and former Lotus colleague, Martin Ogilvie, to ask if he would be willing to (re-)design it. Ogilvie was a little busy building a hillclimb car, so Howard-Chappell made him a deal – you design the Ferrari and Prodrive will build your hillclimb racer.

The arrival of the subsequent Ferrari did just what Ratel required. Although the car, first under the BMS Scuderia Italia team and later others, dominated races against the likes of the Dodge Viper and Lister Storm, it was a catalyst to success.

SRO / DPPI

Prodrive developed the Ferrari 550 Maranello, a car that helped return GT racing to where it belonged. Ferrari responded with its own 575 and others, including Lamborghini and Maserati, later followed

Even Ferrari, who had campaigned against the idea of tuners creating racecars, was spurred into action. Not supporting Prodrive, of course, the Italian manufacturer produced the 575. The Brits, of course, took no satisfaction at all from the fact the works 575 never came close to the success of their own V12 Ferrari!

The 550 Maranello was the car that took on Corvette in the early noughties. Yellow vs red, V8 vs V12, Italy vs America. No one who saw those races can ever forget them.

From the 550 came the Ferrari 575, and the Maserati MC12, and the GT racing scene flourished. Nissan joined, as did the Ford GT through the Swiss Matech team. Hans Reiter developed the Lamborghini Murciélago and continued to race the raging bull through to the days of the Huracán, when the manufacturer finally stepped into the limelight in 2014. Its customer racing business is still going strong.

Strength in numbers

Ferrari soon found a client base in the N-GT class with its 360 Modena. Its customers competing in Ferrari Challenge could race internationally if they wanted to, and many did. Through the 458 and into the 488, the customer racing division, Corse Clienti, continued to grow in strength and depth. Today, the company cannot build enough 296 GT3s. Whether Ferrari cares to admit it or not, it all started with Ratel's vision for allowing tuners to develop cars.

Behind the idea was the theory that professional race teams *needed* cars, and *wanted* to race. Now rallying finds itself in the same position. It doesn't have a big grid, it no longer has the manufacturer support as Hyundai's involvement has a huge question mark over its roof, but it does have a dedicated fan base, it does have teams and it does *need* some hardware. It just needs a little push to get over the tuner hurdle to thrive. When it does, firms such as M-Sport or Prodrive would be capable of building spectacular cars.

The WRC's other option is to promote the thriving Rally2 teams to the top class. Ratel has done that before too, and now his GT3 baby is racing at Le Mans. Rallying, and racing, can learn from the sport's history, and be successful.

Manufacturers wanted to retain control, and the last thing they wanted was for someone else to create a race version of their own product

Ride of the Valkyries

Aston Martin's new LMH car made its competition debut at the opening round of the WEC in Qatar. Racecar *was there to track its progress*

By ANDREW COTTON

Aston Martin is the first LMH manufacturer to meet the criteria of both the WEC and the IMSA Sportscar Championship

Its name is steeped in Norse mythology. The Valkyries were believed to decide who should live and who should die on the battlefield. They were also beings that transported the fallen to Valhalla, where warriors would fight during the day and feast all night. Perhaps appropriate, then, that Aston Martin's Valkyrie should carry the name forward into the 24 Hours of Le Mans.

Originally scheduled to race for the first time in January 2025, at the 24 Hours of Daytona, the LMH-spec Valkyrie's first competitive steps were not taken until late February, when two cars made their long-awaited debut at the FIA World Endurance Championship season opener in Qatar.

Aston Martin is the third constructor to race a non-hybrid LMH car in the WEC, after Glickenhaus and ByKolles, neither of which is on the grid any longer. It is also the first mainstream brand to commit to the Hypercar class with a non-hybrid. All other OEMs have either built their own hybrids or developed LMDh cars which use a spec hybrid package.

Crucially, Aston Martin is the first LMH manufacturer to meet the criteria of both the WEC and the IMSA Sportscar Championship in the United States. The Valkyrie will, therefore, break new ground as the first LMH to race in IMSA. It will be run there, and in the WEC, by The Heart of Racing, an American team backed by video game developer Gabe Newell, which has fielded Aston Martin Vantage GT3s in recent years and also helped to fund the LMH Valkyrie project.

The Qatar race was the first time that The Heart of Racing ran two Valkyrie prototypes at the same time, and faced the usual stresses of doing so in competition alongside its GT3 programme

However, to make the grid at the opening round of the IMSA season at Daytona, the Valkyrie would need to have been homologated long before the Christmas break, and spare parts prepared throughout that same period. Therefore, the 1812km race in the heat of the Qatari desert a month later was considered more feasible.

With Le Mans as the cornerstone of the WEC season in mid-June, the three races before it will be critical. Aston Martin completed around 15,000kms of testing ahead of the Valkyrie's debut, but knew that even decent mileage would be no substitute for running in anger. With no competition data to draw from, the Aston Martin was performance balanced against the Toyota GR010 Hybrid for its first race. With a rolling three-race average, it will take until after Spa in May for the FIA and ACO to have all the data that it needs to balance the car correctly.

Road car base

The base of the Valkyrie competition machine, according to Aston Martin's head of endurance, Adam Carter, is a combination of the £2.5 million ($3.1 million) Valkyrie road car and the track-only Valkyrie AMR-Pro. There are fundamental differences that go far beyond a straightforward road to race adaptation. For example, the Valkyrie racecar does not have active suspension, or active aero; it does not have a hybrid system on the rear axle and the aerodynamics are new, designed to work in extreme temperatures and conditions and to meet the performance windows as required by the BoP.

'In terms of re-positioning [the car's aerodynamics] in the performance window, a lot of that is on the underfloor and the front wing area'

Adam Carter, head of endurance motorsport at Aston Martin

Aston and its design partner, Multimatic, which is also involved in the development and running of the car alongside The Heart of Racing team, took the production car tub, adapted the suspension pick-up points and replaced the road car's active suspension with a traditional, passive, double wishbone set up.

While the surface of the Valkyrie has remained largely faithful to the production car, downforce had to be shed to meet the lift / drag targets set by the regulations.

Aston Martin therefore focused on developing everything under the bodywork, starting from the front wing. 'We have had to re-define the aerodynamics of the car,' says Carter. 'The intention was to leave as much of the outward facing surfaces as the [road car] because it is important to represent the Valkyrie wherever possible.

'In terms of re-positioning it in the performance window, a lot of that is on the underfloor and the front wing area. You also see, as per the other LMH / LMDh cars, an amount of work put in place around the aerodynamic stability criteria.'

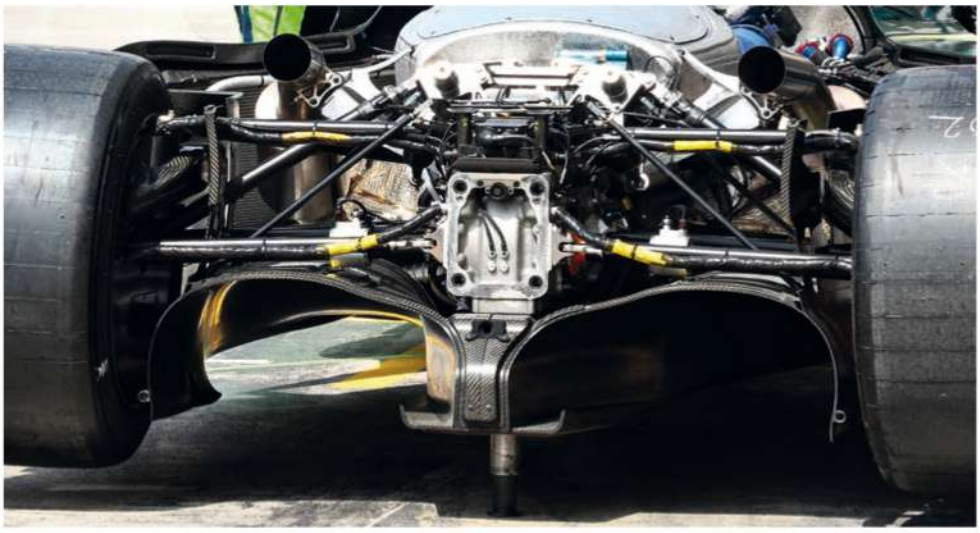
When asked to put a figure on the amount of downforce shed from the production car to the racecar, Carter simply said that with the loss of active suspension, there was no accurate direct comparison.

Large strakes over the roof, the rear wing and the rear wing end plates helped achieve the required stability targets for the car in yaw. Other significant departures from the production car can be seen around the front wheelarches: the louvres that reduce pressure over the front wheels are more pronounced on the race version.

'The thermal management demands of an endurance racecar operating at the peak of its limit over multiple, wide-ranging boundary conditions, such as high ambient conditions, debris consequences and so on, require a different strategy to that of the road car,' adds Carter, pointing out that ambient temperatures at the WEC's Circuit of the Americas round in 2024 reached around 40degC.

Teams are only allowed to adjust one aerodynamic device and can choose whether this goes on the front or rear wing. Aston Martin opted for a front-adjustable device, like the Glickenhaus 007 Pipo that was the first non-hybrid LMH out of the gates in 2021.

Managing tyre wear on a rubbered-in track, while also running in traffic, meant the engineering team was on a steep learning curve during the debut race, so expectations were kept in check



The LMH version sees the road car's active suspension replaced with a traditional, passive, double wishbone arrangement

'We have taken the opportunity to reduce engine speed to help develop the torque curve and reduce frictional losses to increase efficiency for the level of power that is permitted'

Adam Carter

'The reason we chose that is because the Hypercar category rewards race optimisation and execution, and we felt a front-adjustable device was the most appropriate option and gave the most opportunity in racing scenarios,' explains Carter.

Power down

Cosworth also had its work cut out, as it needed to remove more than 300bhp from the thousand-horsepower, 6.5 litre V12 engine it had created. Downgrading the V12 wasn't the work of a moment, and the task was carried out under a sensitive context. When Aston first announced it would enter Hypercar with the Valkyrie in 2018, the maximum power output was increased by just over 100bhp (to 785bhp) to accommodate it. That forced other manufacturers to change their engine concepts. Glickenhaus even switched suppliers, scrapping a proposed link up with Alfa Romeo, to find something that could meet the new target. However, when Aston rowed back on its commitment to Hypercar nearly two years later, the maximum output was returned to 520kW, under 700bhp.

The removal of the rear hybrid system helped shed some of the excess power, and had the happy by-product of meaning the racecar does not have the complication, weight and cooling demands that come with such a feature. All the time it is on track, the LMH Valkyrie will run without hybrid power. However, it is technically a mild hybrid because it will pull away from the pit stall on electric power, using the car's onboard 48V battery, before the engine kicks in.

'Because of the power reduction, we have taken the opportunity to reduce engine speed to help develop the torque curve and reduce frictional losses to increase efficiency for the level of power that is permitted,' says Carter. 'This also presented an opportunity to tune the torque curve, which involved changes to the valvetrain.'

Reducing the rev limit from 11,000rpm in the production car to 9000rpm in the racing version has allowed the team to improve

TECH SPEC

Homologated to ACO / FIA Le Mans Hypercar regulations

ENGINE
6.5-litre V12, naturally aspirated (based on Valkyrie production road car engine)
Power 500kW +/-20kW*
Weight >165kg*
Dry sump oil system
Bespoke race optimised exhaust system

FUEL SYSTEM
Fuel cell to FIA safety standards
Krontec single point rapid refuelling coupling

DRIVELINE / TRANSMISSION
Rear-wheel drive
Xtrac seven speed (+ reverse) sequential transmission
AP Racing carbon / carbon multi-plate clutch
Mechanical limited slip diff' with externally adjustable preload
Semi-automatic paddle shift gear change
Direct acting electric gear shift actuator
Electric pit lane pull away starter motor
Mandatory driveshaft torque sensors

BRAKES
Bespoke Alcon six-piston calipers
AP Racing carbon / carbon front and rear discs and pads
Driver-adjustable front / rear brake bias
CFD optimised brake cooling ducts

CHASSIS
Carbon monocoque survival cell to FIA safety standards
High-speed pneumatic jack system

STEERING
Power-assisted steering
Carbon fibre, six-paddle, quick release steering wheel

SUSPENSION
Double wishbone front and rear
Pushrod-actuated torsion bar springs front and rear with adjustable side and central dampers
Adjustable anti-roll bars

WHEELS
Forged aluminium 12.5 x 18in front; 14 x 18in rear
Captive wheel nut design

TYRES
Michelin Pilot Sport 29/71-18 front; 34/71-18 rear

COCKPIT
Optimised for safety, driver access and visibility
Carbon fibre race seat with shoulder support; mandatory headrest padding
Six-point Schroth FIA 8853 safety harness
FIA 8865 fire extinguisher system
Customisable driver display and shift lights integrated into the steering wheel
Additional dashboard-mounted shift lights and marshalling display
Mandatory day / night mode rear view camera
Air conditioning
Electrically-operated driver drinks system

BODYWORK
Aerodynamics developed to meet regulation homologation criteria
Single homologated adjustable aerodynamic device (AAD)
Venturi tunnel underbody
Two-element front and rear wings
Quickchange front and rear bodywork
Front and rear impact absorbing structures
Mandatory spectator information display panel
High visibility rain / fog lights integrated into rear wing end plates

WEIGHT
1030kg* without driver and fuel (permitted minimum)

Though the similarities to the road car are clear to see, the aerodynamics of the race version had to be re-designed. Among the noticeable differences are the more pronounced openings over the front wheels to channel air efficiently

reliability expectations, with headroom to increase that limit to 9500rpm if needed.

Hitting that torque curve is something all Hypercar manufacturers have invested time, money and effort in achieving. The closer a car can run to the limit in all conditions, the faster it will be around the lap. For some, failing to get on top of ride control meant having to cut power over bumps and kerbs to avoid receiving a penalty for exceeding the limit. The question is whether it is easier to hit the prescribed limit using hybrid energy, as the LMDh cars can do, or through advanced engine management.

'All engineering programmes are a balance of compromises,' explains Carter. 'Designing a racecar is no different. There are advantages and disadvantages to different systems. We are confident the decisions we've taken that result in the Valkyrie are ones of a highly performant vehicle. We respect and support the methods and decisions of the FIA, ACO and IMSA and their continued work as they create a level playing field for us all to compete on.'

Ultimately, the requirement for a non-hybrid LMH car to have a front-mounted motor was the death knell for hybrid in the Valkyrie racer

Naturally aspirated engines, particularly a V12, have smooth torque delivery and a high response rate, while with a turbo it is better to tune to different atmospheric conditions. For hybrids, meanwhile, the engineers have to synchronise the ICE with the car's electrical energy, which is at least one complication Aston Martin does not have to worry about.

Non-hybrid contender

The Valkyrie has created something of a stir in the paddock, with some manufacturers privately stating they are unhappy another manufacturer is allowed to race without a hybrid system. But Aston is not breaking any rules by doing so. Ultimately, the requirement for a non-hybrid LMH car to have a front-mounted motor was the death knell for hybrid in the Valkyrie racer.

The production Valkyrie has a rear-mounted hybrid motor, so creating a front-mounted system would have meant a departure from the road car values, and too much work around the front of the cockpit. 'Hybrids come with a significant mass consequence, so to take a car which is also carrying that V12 power unit, which also carries mass trade as well, it becomes a different challenge,' confirms Carter. 'Also, if you look at the hybrid system on the Valkyrie, it is actually on the rear axle, not the front, so you are into different chassis and monocoque concepts, and you are also changing the front end, which comes with even further mass.

'If you take the hybrid system and reflect the Valkyrie, the cooling demands different packaging, so you would be packaging the entire car in a different way.'

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Others have expressed frustration that the front hybrid system can only be used at speeds over 160-190km/h. This is a rule designed to balance the four-wheel drive LMH cars against the two-wheel drive LMDh and non-hybrid LMH cars. Some have gone as far as calling it the most expensive ballast ever carried in a racecar.

Coding collective

One of the key differences in the car is the choice of supplier for the ECU. Although Aston Martin does not have a hybrid system to code, there is still a lot of work to be undertaken by its partner, Cosworth. 'Coding is collective, and we have multiple partners within the programme, so The Heart of Racing, Multimatic and Cosworth,' says Carter. 'Having a Cosworth ECU and power unit means we are working with the same people used to the same capabilities and speaking the same language.

'For us, it was a natural partnership to bring them together, and there are clear synergies in working with partners rather than suppliers.'

The team will race the Valkyrie at the 12 Hours of Sebring in the US and, at the same time, continue preparation in the WEC to be ready to take on the challenge of Le Mans in June. The car has already shown early promise and the team will now focus on building on what it learned in Qatar.

Expectations in check

The Aston Martin Valkyrie LMH was never expected to set the world alight when it hit the track for the first time in anger in Qatar. For starters, the Balance of Performance regulations were set against it due to the lack of data (see story on p14), but it was also the first time the brand new car had run on a track that was properly rubbered in, along with other Hypercars and a full field of GT3s. So for the drivers, they also had traffic to contend with.

Qatar was also the first time The Heart of Racing had run both Valkyries at the same time, and so normal race challenges such as spare parts and set-up parameters had to be finalised on site. The race pace of the Aston was, on average, one second off the Toyota, which was its reference car in the BoP calculations. Although one Valkyrie had a problem with a door coming open and another suffered electrical issues, it was a reasonably steady debut. 'We have to keep in check our expectations,' said Ian James, team principal at The Heart of Racing, ahead of the race. 'Race pace is not too bad, we will hang onto the lead lap as long as we can, complete the distance, collect data for the championship and learn. We are learning in anger now, and will see what we can pick up in the future. Just getting to the end of the race is like a win for us.

'Operationally, we need to maintain efficiency, get the data off the car, get the drivers briefed and get out there for the next session, and we need to get good at it. That is something we haven't focused on before because we've been doing durability and long run performance testing, so we are learning all the time. The guys took notes of the cars around them, how they build up and cool their tyres down, so at Imola we will be stronger.'

'Ultimately, we have not identified any differences in car behaviour to what were expected,' added Adam Carter, Aston Martin's head of endurance. 'It has been an opportunity to measure where we are on absolute pace, and we are about where we thought we would be at this point.

'[Qatar] is a difficult track to overtake on. The drivers are backing off and positioning themselves to look after the tyres, but also to not lose too much load or power. It has all been done in the testing programme, so there's nothing untoward in that.'

The cars finished at the back of the Hypercar field on their race debut with one car retiring and the other finished 23 laps down, but Qatar was just the start of a period of intensive learning and development, with undoubtedly more to come with the IMSA and WEC races ahead of the Valkyrie's debut at Le Mans in June.

Though the two Valkyries finished at the back of the Hypercar field on their debut in Qatar, with one suffering a door malfunction, the team was largely happy with their performance, and is now looking to build on that for the next round at Imola in April

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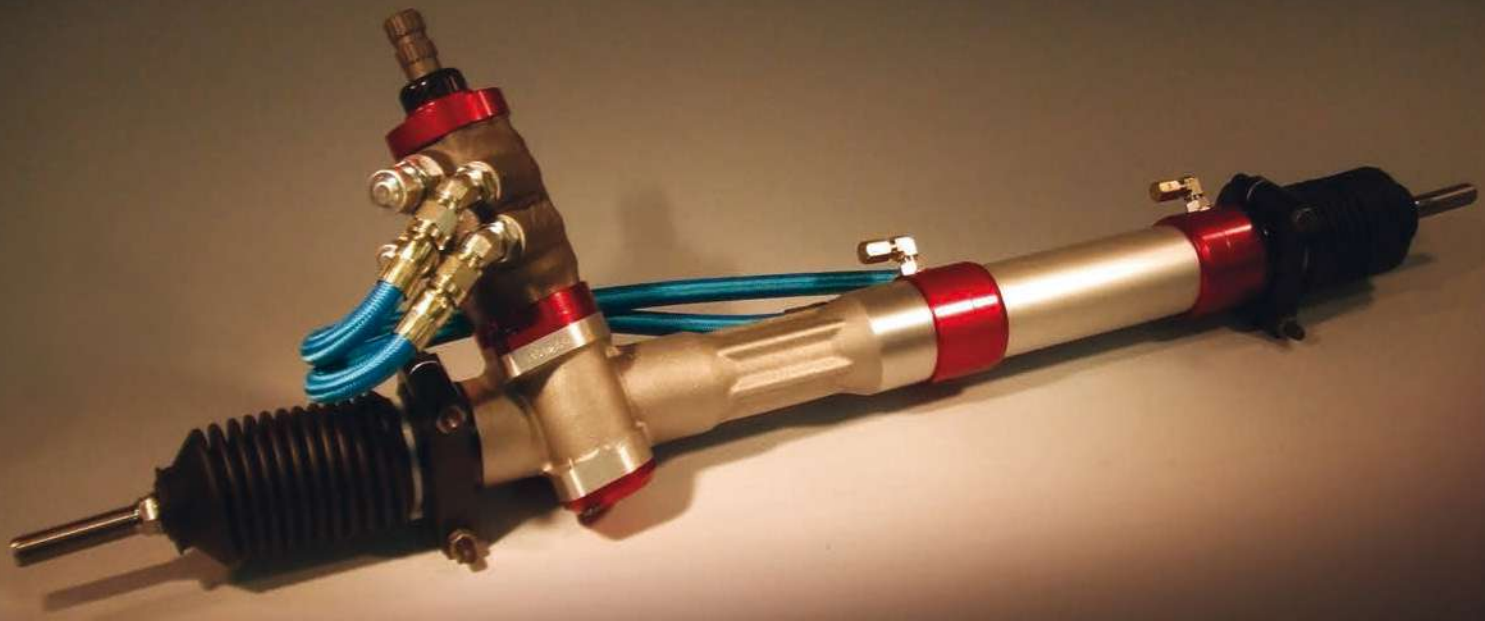

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A question of balance

A new season, a new BoP for the WEC, and it certainly hasn't become any less complicated

By ANDREW COTTON

The FIA World Endurance Championship has updated its Balance of Performance (BoP) system with what it says is a more precise and detailed set of regulations. The work is done jointly between the FIA and the ACO, relying heavily on algorithms and AI. Responding to requests for increased transparency, selected details are then shared with the Hypercar manufacturers, but the organisers still keep certain data hidden to prevent anybody from playing the system.

Underlying the balancing act is the need to give all competitors the chance to win, while preventing them from pouring unnecessary money into development. The latter is relatively straightforward – any evolution made to a car leads to a penalty in the system for a number of races. The former is the controversial element of the process.

The FIA and ACO held eight technical working group meetings over the winter with the manufacturers, and say they broadly have agreement from them all for the updated system. At the opening race of the 2025 WEC season in Qatar, a media workshop was held to explain how the details have changed.

Weight for it

New for 2025, then, is the introduction of an average driver weight in the car, set at 82kg, in line with other FIA championships. That should prevent the extreme dieting and weight loss some of the heavier drivers went through in 2024. However, the laws of unintended consequences immediately came into play. In qualifying, the cars now have a different minimum weight, depending on who is driving the car, so the average driver weight only comes into play during the race.

'At this stage, because the BoP calculation is now quite precise, we cannot forget the average crew weight,' says ACO competition director, Thierry Bouvet. 'We looked at how to individually balance [the drivers], but having removable ballast would not be a good thing to do as you need to fix it correctly to the cars.

'Changing the power, or revs [according to driver weight], would change the raceability of the car and the drivers will get the same trophy at the end of the race, so we wanted to balance the cars [rather than the drivers].'

The move was widely welcomed in the paddock, although some pointed out that a heavier driver will still carry a performance penalty in the race compared to lighter team-mates. Not only will they carry their own extra weight, but also the ballast. However, with the entire car being balanced against lighter driver crews, it is a compromise they are willing to accept.

Fuel load

The weight of the cars has always been a contentious issue in the WEC. Having gone as far into the detail as driver weight, other weight-contributing factors also have to come into play, notably the brake-specific fuel consumption of each car.

This is the calorific value of the fuel, and cars with less efficient engines carry a higher fuel load at the start of each stint, including the opening one of the race. As all engines are homologated and cannot be touched, the FIA and ACO instead look at a point in the stint where the cars match, and balance that.

Mid-way through a stint, the fuel load (and therefore overall weight of the car) is calculated, and the difference in weight between the cars is taken into account. The more efficient cars then carry a small amount of ballast to compensate for their lighter fuel load at this stage. This calculation is included in the BoP table issued before every race. In qualifying, however, the more efficient cars will not carry this ballast.

New for 2025 is the introduction of an average driver weight in the car, set at 82kg

'The aim is to avoid a technological war on engine efficiency,' says Thomas Chevaucher, FIA technical engineering director. 'We know that it is essential to have a highly efficient engine to be able to compete in the category but, once they reach a reasonable threshold, we don't want to push them to go any further because costs quickly sky rocket.

'We consider the average weight of the car during its stint, or qualifying run, and we will compensate according to the fuel requirements of each car. We will remove some weight from the least efficient cars because they carry more fuel for the race. This was already taken into account last year, but it is a new feature for the qualifying sessions this year.

'Previously, the situation was the same in the race and in qualifying but, as we are trying to make things as fair as possible, we are using a different figure for qualifying because the stints are shorter and so is the amount of fuel.'

Moveable averages

Making the issue even more complicated is the average stint performance of the cars during a race. Typically, in 2024, the FIA and ACO only looked at the fastest 20 per cent of laps, which gives an indication of the absolute potential of each car in race conditions. However, that has now expanded to cover the average 60 per cent fastest laps, which also takes into account team performance and tyre wear. On top of that, the FIA and ACO will take into account the ten quickest laps, which again shows the potential of the car.

'There were slight differences between the LMH and LMDh cars, so we needed to take into account more laps to remove these small differences,' recounts Bouvet. 'It was very collaborative with all manufacturers and we took their feedback into consideration.'

The averages will be taken from the last three WEC races where data is available. For Qatar, therefore, the organisers re-calculated the performance of the cars at Austin, Fuji and Bahrain 2024 to create the BoP table for the

Cars that introduce aerodynamic updates, such as the Porsche 963 pictured here which modified its rear diffuser for 2025, must now pay a small penalty for early season races, and at Le Mans

2025 opener, and will have a rolling average as further races unfold. For a new car such as the Aston Martin Valkyrie, it will be balanced against the best car overall until it has its own complete data.

For the first three races of this year, then, the Aston Martin will run at a disadvantage compared to the others as it clearly cannot match the best on the grid at such an early stage in its development lifespan.

Meanwhile, Hypercars that have had an aero update from last year, such as the Porsche 963, will carry a lap time penalty of 0.3 per cent for the first race with the new aero kit, 0.2 per cent for the second and 0.1 per cent for the third, by which time the organisation will have a clearer picture of how the car performs with its adjusted features.

For the LM GT3 class, the top 60 per cent fastest laps of each car will be looked at in the BoP calculations, but not the outright fastest ten. With professional and amateur drivers in the field, it was deemed unnecessary to factor in absolute performance.

Secrecy in France

The 24 Hours of Le Mans is a separate story. There, the FIA and ACO have kept secret their criteria for fear that the teams will play the system in order to win the biggest race of the WEC season. The regulatory bodies have said they will not use last year's race data, due to car updates that have come for 2025, and

'The race is not about the figures, it is about drivers, conditions, a lot of things, and it was artificial to keep them inside a window that we don't control'

Thomas Chevaucher, FIA technical engineering director

improvements made by the teams. They will also not use data from the first three races. At time of writing, they have not confirmed which figures will be used to calculate the BoP for the French event. Likely it will be a combination of them all.

Although the maximum speed of cars at Le Mans is not being capped, a compensation will now be given to those that carry more drag. However, as some teams have brought aero updates, they will not receive the same compensation. 'We are not introducing a maximum top speed at Le Mans, but we will compensate for top speed between cars with known bodywork,' says Bouvet.

The FIA and ACO have now shared the data collected for cars with the individual manufacturers. So Ferrari will have access to the BoP data field collected for its car, and will be able to work out its own figures.

'We don't share the other cars' data with other manufacturers,' points out Bouvet. 'So only the individual team can check what they are doing with their car.'

An interesting point to note here is that the FIA and ACO have put a value on the average performance difference between two cars in the same team, of between 0.3 and 0.4 per cent, on average. While the organisers are trying to balance all cars to a lap time, they can only take into account the *best* car from a team: the one that has made the best choice on set-up, tyres and track position, as well as driver performance at any given race.

'We consider the figures after the race, but the race is not about the figures,' explains Chevaucher. 'It is about drivers, conditions, a lot of things, and it was artificial to keep them inside a window that we don't control.'

For 2026, when all cars will only test at the Windshear wind tunnel in North Carolina, rather than at Sauber in Switzerland, which was previously the FIA's controlled-condition facility, there will be an offset in the aerodynamic performance window to take into account the figures gathered at the different tunnel.

This has apparently led some teams to delay aerodynamic updates until 2026 to prevent more testing, (and subsequent penalties) instead of using their permitted modifications early.

McLaren prevailed in a tight F1 battle last year, and expects the field to again be close in the final season of the current regulations

Closest season yet?

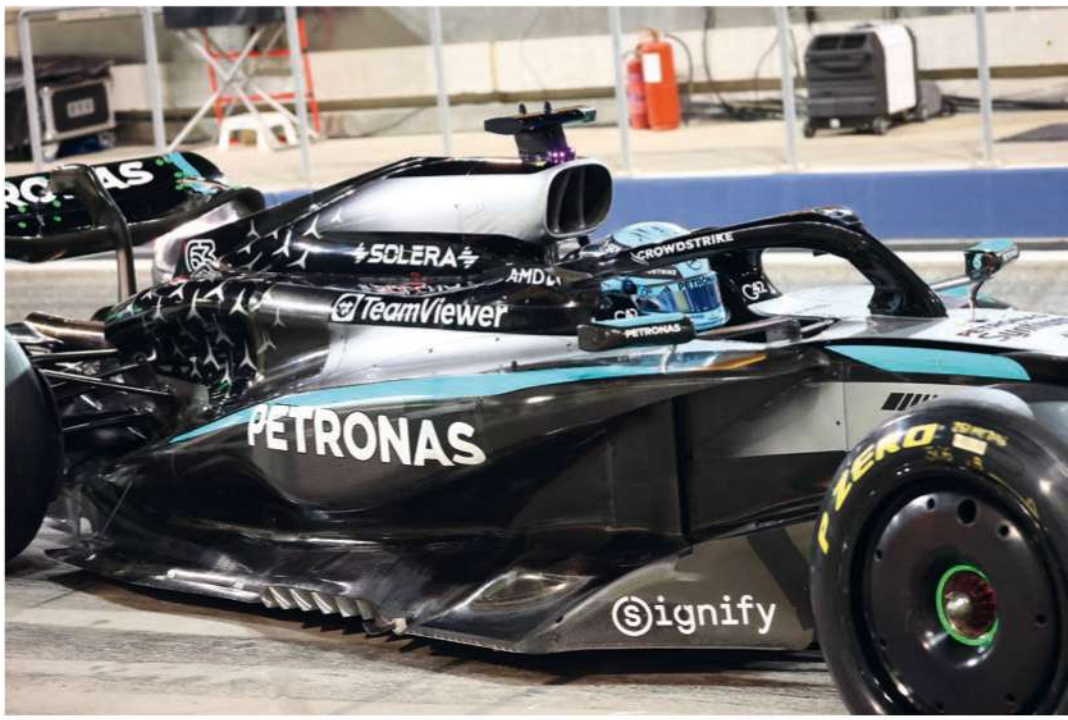
The final season of an F1 rule set always promises close racing. Racecar *assesses the priorities for each team heading into 2025*

By DANIEL LLOYD

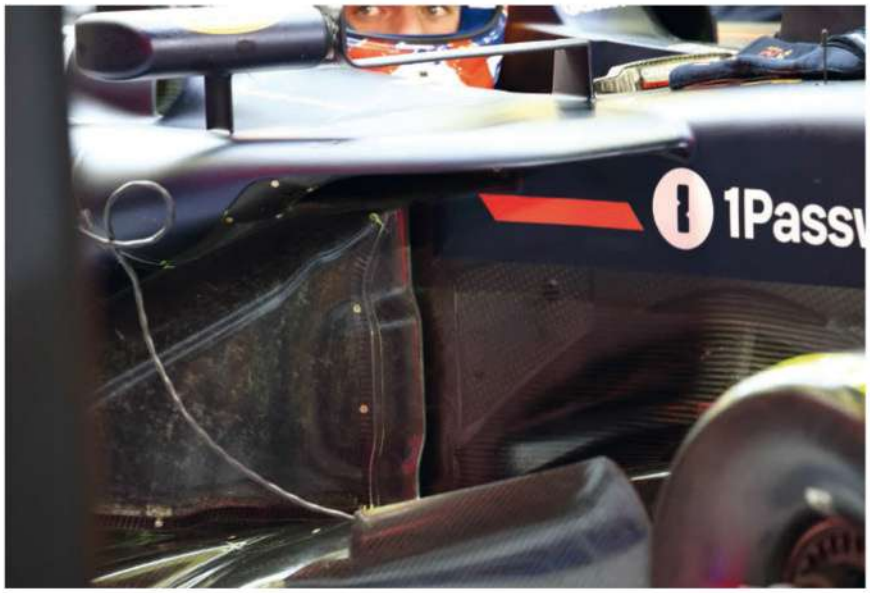
That the field would close up in the final stages has been the hope since the early days of the latest Formula 1 rules cycle, which arrived in 2022 off the back of a cracker in 2021 and is now approaching its conclusion. After two seasons of Red Bull dominance, patient F1 fans were rewarded with a fierce battle for the constructors' title last year. McLaren overcame Red Bull to win its first championship in 26 years, while Ferrari also chimed in on the battle. Mercedes won races, too. Between that trio, seven different drivers stood atop the podium in one exciting season.

The 2025 campaign therefore has a lot to live up to, but logic dictates it has a good chance of providing a nail-biting finish the fans, and everyone involved, are hoping for. The usual trend of development in F1 is for designs to funnel down as the regulations mature, homing in on the final year when all teams have more knowledge about their cars than at any other point.

McLaren is entering unfamiliar territory this year, as it will be the first time it has sought to defend a constructors' title this century



Mercedes has a number of specific traits it wants to solve on the W16 this season, including turn-in for slow corners



Red Bull continues to lead the way in frontal sidepod design, as evidenced by the thin strip of a vertical cooling inlet

We are a long way from the first pre-season test of 2022 at Barcelona when the design net was at its widest and teams were first encountering the challenges of running ground-effect cars. They came with a variety of concepts, most famously Mercedes and its so-called 'zero pod'. Four years on, designs have largely converged on a similar philosophy. For example, all except Alpine and Haas use a version of the overhanging sidepod inlet style and deep undercut that became fashionable. However, there are still some interesting features cropping up here and there, showing teams have continued to find minor gains within the regulations, despite their resources shifting towards the 2026 rule set.

The first glimpse of the fresh batch of F1 cars came when McLaren shook down its title defender, the MCL39, at a grey Silverstone on 13 February. The British team's car revealed a refreshingly high amount of detail, although unfortunately this standard was not upheld by all that followed. It meant the first proper look at the 2025 grid came during pre-season testing, held at Bahrain International Circuit over three days in late February.

It was unusually chilly in the island desert nation. Ambient temperatures of around 14degC meant the track was only just above 20degC when the first session got under way. This made it challenging to read anything into who would be strong at the Bahrain Grand Prix in mid-April. Last year, the test and race sessions ran back to back, but the timing of Ramadan in 2025 meant conditions shifted dramatically between visits this time. Also, inconsistent conditions over the three days made it hard to even figure out a pecking order from the 24 hours of running available. Day one was cold and windy, while light rain impacted day two as only Aston Martin and Haas had brought intermediate tyres. Then the sun finally came out on day three. Not the easiest backdrop to a test where teams were running different power unit modes and fuel levels.

Tyre talk

Teams were free to choose tyres from Pirelli's six-compound slick range. Most opted to use the C3 medium on day one as it was the one that had been modified the least since last year, as part of the tyre manufacturer's updates to reduce graining.

'We compared the long runs with different teams [but] we have to pay attention to the time of day when they set the lap times,' warned Pirelli motorsport director, Mario Isola.

Day three was the most representative from a tyre perspective, even if the temperature was still nowhere near what it will be for the Bahrain GP. Nevertheless, Pirelli felt the data validated its target of updating the C2 to be more equally spaced, in degradation and performance, between the C1 hard and the C3 medium. This update was based on Pirelli observing that teams were often put off running the C2 in races last year.

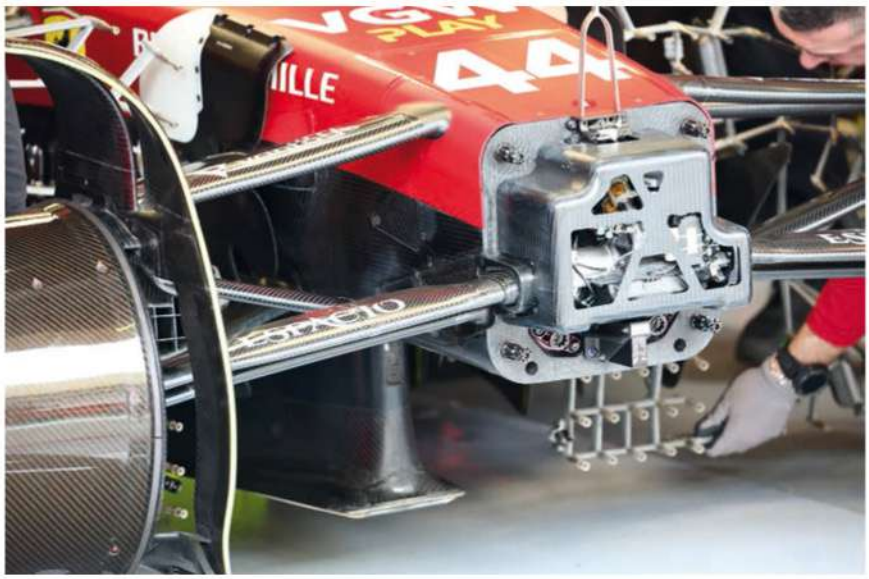
'We had the C2 quite close to the C1, and far from the C3,' says Isola. 'That is probably why, during the race, most teams had a strategy of C3, C1, C1 because the C2 was very close in terms of performance, but with higher degradation. So, there was no incentive to use the C2. That's why we wanted to move the C2 closer to the C3.'

There was very little running on the softest of the three compounds because they were not suited to the notoriously harsh Bahrain track surface. Only Ferrari and Williams picked the new, ultra-soft C6, but did not use it.

Unfamiliar territory

McLaren is entering unfamiliar territory this year, as it will be the first time it has sought to defend a constructors' title this century. The Woking-based outfit has responded to the task by evolving its proven race winner into the MCL39, which it hopes will pick up where its MCL38 predecessor left off.

A supporting impression was given on the first day of testing, when Lando Norris set the fastest lap, and on day two when he completed an impressive long run. Not that lap times mean a great deal during testing, when teams are more bothered about seeing if their cars return performance metrics that match up with their simulated data.



The new Ferrari pull rod is visible extending rearward here, between the upper and lower front suspension wishbones

Teams continue to investigate the most efficient ways of drawing air into their cooling radiators, while at the same time maximising the volume available for air to pass into the downforce-inducing floor and around the sidepods

The McLaren MCL39 features adjusted suspension geometries both at the front and rear, with the wishbones mounted further apart to aid platform control. The aim is to promote anti-dive so the ride height doesn't shift and compromise the car's potency in generating ground effect.

McLaren was one of the teams that successfully investigated the flexibility of front wing components last season. It benefited to the extent that the FIA was encouraged to look at how much flexibility should be allowed and, after meetings spanning the winter break, it reduced the amount of allowable flex by 5mm. This will take effect at the Spanish Grand Prix in May.

Carbon fibre bodywork *needs* some flexibility to ensure it doesn't break under aerodynamic load, but within that necessary flexibility lies performance potential. Teams utilise it in different ways but, essentially, the rotation of the front wing elements alters the airflow in a way that sacrifices some downforce to aid rearward balance on corner entry and front balance on corner exit.

One of the main engineering programmes for Ferrari ahead of the 2025 season was switching from push-rod to pull-rod front suspension

At testing, Norris reported that he was struggling with rear-end instability. McLaren wasn't just looking at the rear, though, for it has also been working on improving its car's mid-corner behaviour. Norris' comments may have stood out because rear instability is a characteristic often associated with the Bahrain track.

'According to what we have seen so far, and the data we had through car development, if anything, we think we have improved from this point of view,' said McLaren team principal, Andrea Stella, 'but you always improve by a quantity that is never going to make this kind of problem disappear. The only time I saw something change as dramatically as there [being] no problems with traction any more, is when we had the exhaust [blown diffuser] effect [in] 2011-2012. I was at my previous team [Ferrari] and we introduced the exhaust effect from one session to the other, and the car was like, no problem with traction any more!

'It's a dramatic change of aerodynamic behaviour. We did what you can do inside the scope of the regulations, which are fixed, then you are always going to suffer the same limitation. Ultimately, you need to reduce those limitations more and more.'

Key challengers

McLaren is expected to face its strongest competition from last year's main contenders: Red Bull, Ferrari and Mercedes. One of the main engineering programmes for Ferrari ahead of the 2025 season was switching from push-rod to pull-rod front suspension. These rods pivot into the chassis, enabling the car platform to run smoothly over bumps and kerbs. A pull-rod layout, where the rod attached to the wheel from a mounting point low in the chassis, offers aerodynamic benefits over a pushrod, minimising disturbance for air heading towards the sidepods. The car also has a slightly lower c of g because of the low rocker placement.

Ferrari stated that the change was made to 'clean up airflow around the car, while also giving scope for further aero development, which had been pretty much exhausted with the previous iteration.' The Italian team was evidently convinced that changing direction, even for just one year, was a necessary move to overcome the dominant McLaren.

Comparing the SF-25 with Ferrari's rivals from last year, the engine cover is broader than those of the McLaren and Red Bull. The Ferrari also has a wider sidepod inlet than the MCL39, while the central ridge of its engine cover has an interesting razorback style, also seen on the Haas VF-25 and Alpine A525. The McLaren has a small, protruding fin that stops midway along the ridge, whereas the Red Bull has a fin that ends in a point, visually similar to FIA Formula 2 machinery.

The Red Bull RB21 was the enigma of pre-season testing, for its aero concept looked much like that of its predecessor. The team prompted further intrigue in Bahrain by fitting the car with a new front wing on day three, suggesting it has more aerodynamic developments up its sleeve.

Red Bull's four-time defending world champion, Max Verstappen, made comments in Bahrain to the effect that the RB21 initially felt more predictable than last year's car.

'I think the direction we're working into is good,' he added. 'We just need to follow that and see how much [more] we can extract. At the moment, it's really early days. There are a lot of things we are still discussing and wanting to improve. I enjoyed it though. That's already a big difference to last year.'

However, there has been some conservatism from the Red Bull camp since. The team's technical director, Pierre Waché, later admitted that the test was 'not as smooth' as he and the group expected: 'It's going in the right direction. Maybe the magnitude of the direction was not as big as what we expected. That is something we have to work on for Melbourne, and maybe for future development.'

Mercedes covered the most ground of any team at testing, amassing 458 laps (around 2478km). It only just pipped Haas in that regard, by a single lap. According to technical director, James Allison, Mercedes' priority for the W16 has been to make it more agile on turn-in for slow corners, as well as reducing its tendency to have a tyre temperature imbalance, which affected the car's consistency over a race weekend.

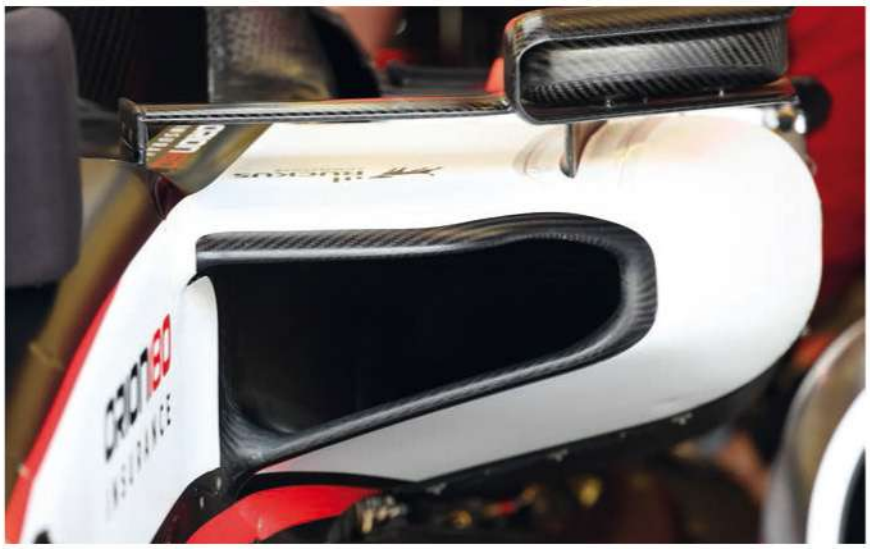
Noticeably, the nose of the W16 now extends all the way down to the end of the front wing, whereas on the W15 it was attached to the second element.

Back on track

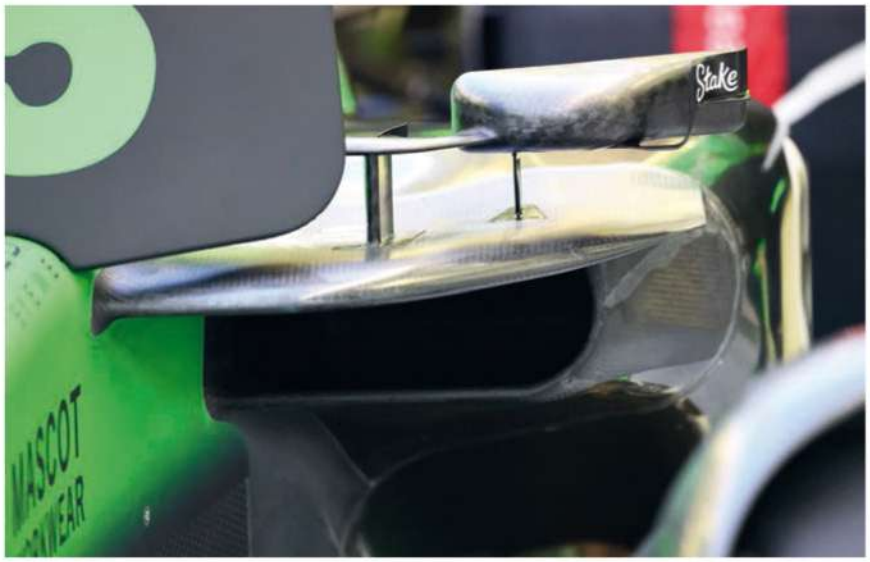
What a difference 12 months can make. This time last year, Williams and Alpine were both fretting, with overweight cars that were off the pace. It felt as though both were staring down the barrel of a potential wooden spoon face-off. Ultimately, they developed their way out of their respective ruts, shedding excess weight and scoring points more regularly, at the expense of Sauber, which ended up last. Alpine even took a double podium at a rainy Brazilian Grand Prix.

That work across the 2024 season has left the two Oxfordshire-based teams in a better position going into 2025. Both had cars that were under the 798kg minimum weight, enabling the engineers to play around with ballast. Williams' pursuit of a lighter chassis for its 2024 car led to the design of other parts being rushed, making it overweight when the season started. The team still has that lighter chassis, but with the excess weight removed from areas, it now has a more compliant car with adjustability depending on the track.

Notably, Williams has switched from pull-rod rear suspension to pushrod. This alteration has been in the works for about a year. Mercedes and one of its other power unit costumers, Aston Martin, adopted the pushrod layout last year in conjunction with a new gearbox, but there weren't enough parts for Williams to join them. So, the FW46 ran the previous season with the previous year's Mercedes gearbox and suspension geometries. The team then had most of 2024 to get accustomed to the mechanical layout of the pushrod design before fitting it to the FW47. The gearbox has been carried over from the Mercedes W16. The suspension links are also from Mercedes, but Williams designs the shrouding, which influences the airflow.



Haas modified its chassis and packaging layout to continue pursuing the sidepod design it had at the end of last year



Sauber introduced some intricate aero features around its wing mirror structure, which is a key aerodynamic component

'The coolers in the sidepods have moved and changed shape to accommodate the cooling flow we need, whilst allowing us more freedom around the top body, controlling that flow into the rear of the car'

Dave Robson, chief engineer at Williams

According to Williams chief engineer, Dave Robson, the suspension internals are a 'mixture' of parts from both parties. A pushrod design is easier to service because the components are housed above the gearbox instead of inside the bellhousing, although it does also raise the c of g.

'Equally, it opens up opportunities to do different things with the internal suspension, the way you spring the system and manage the damping,' says Robson. 'It's also easier to get at, so set-up changes are more straightforward.'

It was Williams' choice to change rear suspension type, but it felt the advantages of doing so outweighed the negatives. In turn, the team has not made significant changes to the internals of the pull-rod front suspension.

The rear bodywork of the FW47 is different to last year, although this isn't entirely linked to the rear suspension change. It is based on a re-packaging of the cooling system, which the team wanted to do last year but couldn't, due to a crash-prone season that also delayed

Williams led testing with the FW47, which sports a new rear suspension layout, a re-arranged cooling system and a ballast margin

Alpine was cautiously optimistic about the A525's potential, after a much more successful pre-season test than last year

Front wing vortex generator detail on the Racing Bulls' VCARB 02

the rollout of its only major performance update. 'The centre line cooler is quite different and moved,' says Robson. 'Also, the coolers in the sidepods have moved and changed shape to accommodate the cooling flow we need, whilst allowing us more freedom around the top body, controlling that flow into the rear of the car. It's not specific to the rear suspension change, not philosophically. The details of it are, so the whole diffuser, suspension, brake duct and lower and top wings work together and are fed off that top body and the sidepods.'

Like Williams, Alpine had a much better pre-season test than last year. The Anglo-French team made relatively few noticeable changes to its car in the off-season, with key components of the A525, such as the front wing and front suspension, looking almost indistinguishable to its predecessor. Some changes could be observed further back on the car, such as a more sculpted rear section of the engine cover with a deeper channel extending behind the twin cooling exits. The sidepod inlet has been made wider and shallower, but is still more visible than the overbite style seen elsewhere.

Under the radar

Racing Bulls could be an under-the-radar challenger to the rejuvenated Williams and Alpine. The VCARB 02 had a solid test, completing the third most laps of all the teams in Bahrain. Its front wing design is based on a concept that was trialled at the 2024 season finale. The team wants its car to have a wider operating window, to make it less track-dependent.

'Our early development work during the 2024 season was reasonable, the update introduced mid-season less so,' said Racing Bulls technical director, Jody Egginton. 'Further updates towards the end of the year delivered quite well, but we didn't understand their nuances until very late in the year and now we've got a better read on them in aero terms over the winter. That means we'll be making much better use of those concepts we brought to the car at the end of 2024.'

Aston Martin now has the services of Adrian Newey available, although he didn't have a say in the AMR25's initial design. The Silverstone-based team has tried to improve downforce in low-speed corners, giving the drivers a more stable aero platform through the different corner phases. Instilling driver confidence is crucial in these regulations, even if there needs to be some compromise on ultimate car performance.

The AMR25 includes some neat winglets around the cockpit to help dictate airflow towards the rear wing. These are also visible on the latest Ferrari. Additionally on the aero side, the upper surface of each sidepod now has a deep channel carved into it.

'Initial feedback from Lance [Stroll] and Fernando [Alonso] suggests we have made progress with the driveability of the car,' reflected Aston Martin F1 CEO, Andy Cowell, 'but we have also discovered areas that could be better and need more focus.'

Ferrari's move to pull-rod front suspension was arguably less of a surprise than the choice of its customer, Haas, to forgo the same system. Since its debut in 2016, the American-owned squad has leaned heavily on Maranello for key parts, including the power unit, gearbox and suspension. However, it decided not to pursue the Ferrari pull-rod suspension configuration for the Haas VF-25.

'You've got to work out the pros and cons,' said team principal, Ayao Komatsu. 'For us, being a small team, if you decided to buy Ferrari's 2025 suspension, you've got to wait until a certain point [to receive it]. Then you suddenly get that influx of information, and you've got to put people [working] on it. The aero then needs to develop around it.

'If we could see there was enough potential we would have done that but, from the study we did, we couldn't. If we took that dip, and took that resource to adjust the new suspension, we didn't see that we could recover enough. So, the decision was taken to just carry on with the current front suspension development. We haven't seen the [performance] ceiling yet. We think we could, ultimately, get to a better place.'

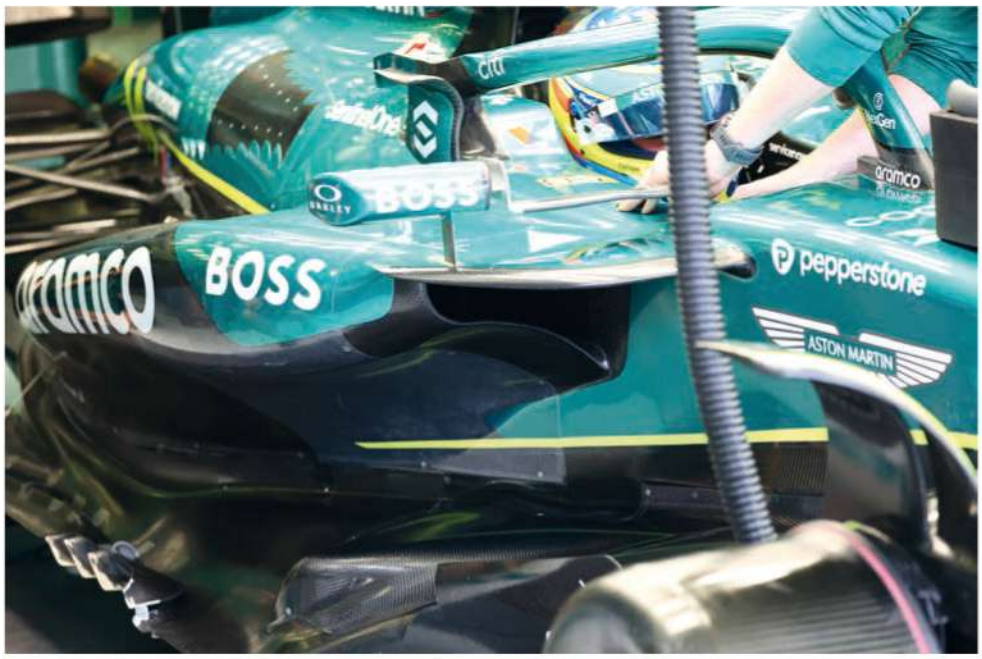
Haas deemed it worthwhile to use this year's Ferrari pull-rod rear suspension, although that call was less drastic because the basic layout remains unchanged.

Building bonds

Adopting an engineering-led focus with Komatu's appointment as team principal last year appeared to help as the VF-24 was more competitive, especially in terms of handling tyre degradation. This season, the focus is on gelling a team that comprises many new engineers, two new drivers, and input from a new technical partner, Toyota Gazoo Racing. That focus was evident on the first two days of testing when Haas prioritised long runs, which didn't reflect well on the VF-25's outright pace but was deemed the best way to build stronger bonds.

Feature-wise, the VF-25 has a tall sidepod inlet, which continues last year's aerodynamic development that started with a substantial underbite before morphing into something closer to the current design from the summer.

'We kind of carried on with last year's direction, but last year we had a certain limitation with the chassis and the layout of electrical boxes,' noted Komatsu. 'Based on what we ran last year, we modified that, the chassis and some of the layout. We just kept developing in that direction.'



Aerodynamic features around the Aston Martin AMR25 cockpit include a neatly curved part next to the rearward Halo attachments

'If you decided to buy Ferrari's 2025 suspension, you've got to wait until a certain point [to receive it]'

Ayao Komatu, Haas team principal

One downside of the VF-25's pre-season running was two instances of bodywork flying off. This first happened during the car's shakedown at Silverstone, and then again on the final day of Bahrain testing. Komatsu said this was down to an unspecified 'modification' made in the off-season that will be addressed, at the likely cost of adding some weight.

The other Ferrari customer, Sauber, came out with some interesting design elements on its C45. As it finished last in the 2024 table, the Swiss team had the largest aerodynamic testing allowance, which is perhaps reflected in its sidepod upper surface being the most elaborate in the field. This bordered a highly detailed sidepod with a very deep undercut to treat airflow off the front wing.

Sauber, which becomes Audi next year, struggled to bring updates out quickly last year, so addressing that is one of the team's aims for 2025. That will be especially pertinent considering teams are looking to thrust all resources onto their 2026 cars as soon as possible. A high-ranking engineer at one team estimated they had concentrated over 80 per cent of their wind tunnel allocation on the 2026 concept during the last two months. Another team principal, however, suggested his team is still hunting gains for this year.

Will the 2025 season be as close as 2024? It is hard to say as new wing flexibility rules will come into effect during the campaign, potentially removing one of McLaren's strengths. In the meantime, the reigning champion's aim is to keep doing what it was good at last year. Ferrari's success will depend on whether its design changes push through the performance ceiling it felt it reached, while Mercedes' aim of improving car consistency will need a few different tracks and conditions to evaluate properly.

Most intriguing will be seeing which of the teams feel confident enough to switch off their 2025 car developments first, as that could give early clues about who might be quickest out of the gate in 2026. As this year will show, F1 is a sport of compromise.

Red Bull's Liam Lawson and his engineers scan the McLaren MCL39 for clues; the Woking team is again looking strong

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Sauber

Joining the party

Being based in Switzerland, Sauber has felt isolated from the bustling Motorsport Valley engineering scene. Getting engineers to relocate to Hinwil has been a challenge that it hopes to address

Sauber is establishing a new UK engineering hub that will be used by the Audi factory F1 team. **Racecar *finds out why***

By DANIEL LLOYD

Currently, there are only two Formula 1 teams without boots on the ground in Motorsport Valley, the colloquial region of central England with the highest concentration of motorsport engineering facilities and talent. The majority are either based there entirely, such as Williams and Aston Martin, or have satellite offices, such as Racing Bulls, which in addition to its Italian headquarters operates an aerodynamics outpost in Milton Keynes.

However, later this year, Ferrari will be the only European squad without a British link because the other one is opening a new technical facility aimed at harnessing the many benefits Motorsport Valley has to offer.

Sauber has been situated in Hinwil, a small town east of Switzerland's largest city, Zürich, for more than 50 years. Its footprint in central Europe has expanded recently, due to its takeover by Audi. The German manufacturer is entering F1 next year, using the Sauber team as a foundation, and has developed its new power unit at a sprawling campus in Neuburg an der Donau near Ingolstadt. The latest move in the project, though, is exploring what Audi can gain from also having a UK presence, by establishing the Sauber Motorsport Technology Centre.

Primary function

The centre will support Sauber's Hinwil headquarters with a range of office-based functions related to optimising vehicle performance and system development. Manufacturing and race team operations will remain at Hinwil, where the team also has a wind tunnel, while powertrain development will continue at Neuburg.

It's noticeable that in recent weeks, Audi and Sauber have been advertising jobs for UK-based design and engineering roles in specialisms such as aero surfaces, software development, vehicle modelling, data analytics and computational fluid dynamics. Some of these tasks, such as CFD, will also continue to be undertaken at Hinwil, but some others will be exclusively in the UK.

Sauber and Audi have been evaluating units in Bicester, Milton Keynes and Silverstone, with the team's technical director, James Key, saying a 'favoured site' has been identified. It is said to be close to sign off, but the team is not yet ready to disclose which of the locations has been selected.

All three are already well known for their F1 activity. Racing Bulls' aero base was in Bicester, before moving closer to its parent team, Red Bull, in Milton Keynes late last year. Silverstone, on the other hand, is home to Aston Martin and the planned Cadillac outfit.

Sauber will initially lease the chosen building, but could purchase it outright in the future. According to Key, it intends to take a 'phased approach' to setting up its UK arm, but that doesn't mean a slow one. The team has set itself the ambitious target of having the first phase operational this summer.

'To begin with, we're going to be looking at some key roles that we know could take a long time to recruit for Switzerland,' says Key. 'We're talking about experienced people. There are specific roles that we should be pinpointing for phase one, which are suited to a lot of development activities. We're talking about aero and vehicle performance.

'There will be some design capability there as well, but really, when you're designing, you need to be close to the parts, too.

'Software development is another area, which is pretty applicable. Methodologies like AFD and CFD can all be worked on there. We'll then grow it over time.'

This phased approach to growth means Key isn't as yet willing to say how many people will eventually be based at the UK centre, since the number is clearly going to increase as employees are added over time.

What has been said is that no roles from Hinwil, which Key describes as 'the mothership', are due to be relocated to the UK, so there is a substantial recruitment push for new talent. The team currently stands at around 400 people, but doesn't want its new UK facility to muscle Hinwil out of the way.

'We're going to end up with what we think is the right balance between the UK and Hinwil,' says Key. 'Ultimately, we're taking it step by step [and] targeting the key areas, which is what we're advertising for right now. We've had a lot of interest, which is really good, but I don't think we can talk about where it's going to end up yet because we've only just started the process.'

Sauber Motorsport Technology Centre UK Limited was incorporated on 23 December 2024, and the team announced its plans in early February 2025. Considering it wants to be up and running this summer, that is a very short timescale before the first day at work. However, Key says discussions had been ongoing long before anything was formalised.

'It's something I was keen to do when I joined the team [in 2023],' he says. 'It was in discussion then, and the only reason it's taken this long is because it's very complicated. You have to determine the legal mechanisms behind it; what the entity is going to be: is it Audi, Sauber or something else? It takes five seconds to register [a company], but the whole legal infrastructure that surrounds it – the different employment laws [in the two countries] mean you've got to have different contracts – makes it a really complex thing to do. There are a great many hoops that have to be jumped through.'

Priority list

Setting up a UK facility was not, however, Sauber's highest priority when Key joined the team. Getting the power unit factory at Neuburg up and running was top of the list.

'It was a medium-term project to jump on as soon as we were able,' confirms Key. 'It was a good thing when Mattia [Binotto, Sauber Motorsport COO and CTO] arrived as he said, "We need a UK office." I was like, I know! Let's jump on it right away.

'Since then, we've been in a better position to tackle it, but it takes several months to go from, let's do this, to actually having an entity that you can then begin to develop. It's a little bit later than we'd have liked, but it's certainly not an afterthought.'

There are multiple driving forces behind the expansion. One is undoubtedly Audi's investment – boosted by the Qatari state wealth fund's acquisition of a minority share in the team last November – which has facilitated growth beyond what Sauber could achieve on its own. That enabled the project to start answering the question of what it is lacking by not having roots in the UK.

'What is clear is we're not in the ecosystem of the majority of the rest of the F1 teams, in terms of the ability to recruit experienced people… without them having to move country'

James Key, technical director at Sauber Motorsport

'What is clear is we're not in the ecosystem of the majority of the rest of the F1 teams, in terms of the ability to recruit experienced people from the industry without them having to move country, which is a big deal,' says Key. 'There is nothing wrong with living in Switzerland, but for many [people] they're going to have family commitments and other things going on that may not make it possible. By having a technical hub in the UK, suddenly we become an option.'

While the UK's motorsport engineering sector has gained a major player, no doubt there will be some disappointment on the central European side that Motorsport Valley has been favoured. However, both Sauber and Audi felt that embedding the team in the UK motorsport sphere is important to ensure competitiveness. Essentially, there was an element of keeping up with the in-crowd.

'There's definitely an element of churn within the industry, of different people moving around different teams,' notes Key. 'That naturally brings with it a certain way of working, with the different cultural aspects of how teams operate. And, of course, the experience you bring as well. I think when you're a little bit isolated from that, as we are in Hinwil, you don't benefit from that much at all when compared to our competitors.

Sauber

Key says that both he and Mattia Binotto were keen for the Sauber / Audi project to have a UK presence. It is understood that no Hinwil positions will be relocated

'They've all got a feel for what other people are doing, and where things are heading, which all counts towards being competitive. As an isolated community, you sort of grow on your own, and maybe it's the case that there's stuff you miss out on.'

Key is quick to dismiss any suggestions that Sauber and Audi's move to the UK has been financially motivated. Wages are lower in the UK than in Switzerland, although Audi successfully negotiated a cost cap increase to account for its higher expenses. Then again, the cost of living is higher in Switzerland than in the UK, which has long been a barrier to Sauber hiring people from Motorsport Valley.

'The calculations are quite complicated,' says Key, 'though it wasn't done for financial reasons at all. It wouldn't have been a sensible way to spend our budget. There is no financial incentive for us, it's an entirely performance-based topic. Can we have a performance differentiator by being present in two places? Maybe. Financially, though, there's really not much in it. If you have some senior roles in technical, it is pretty similar.'

Powerhouse of output

A core aim for the Technical Centre is for it to be autonomous, but it also needs to be on the same page as Hinwil. This is one of the big challenges for any multi-national F1 team.

'The intent is not to have an operation that is working purely under instruction,' confirms Key. 'For the team, it needs to be a powerhouse of output. Obviously, we will align every day with our plans and primary objectives, but we're keen to give the group as much freedom as possible to output performance ideas. A bit of creativity, new directions, very quick throughput and turnaround, such that we've got a really strong, albeit smaller, technical group in the UK who can work to their best to generate performance and improvements for our car.'

Because no manufacturing will be carried out at Sauber's new British campus, the logistical demands of transporting parts between the UK and Europe post-Brexit are mitigated. The focus, therefore, will be on ensuring the UK, Swiss and German departments all communicate well remotely.

'We don't want to be too restrictive,' adds Key. 'I did experience this when I was working at Toro Rosso, but that was before Covid, and before Brexit. It was a slightly different environment then. The objective was the same though – to make it feel like we were sat next door to each other. There were lots of trips backwards and forwards for both sides, to get acquainted, and my experience of that told me you can make this work if you organise and communicate in the right way. That gave us the confidence that we could make a UK facility feel like they're sitting next door to us at Hinwil, and *vice versa*.'

Parallel lines

How do you prepare a NASCAR for the Daytona 500? Racecar *spent a day with the event's most successful team to find out*

By BOZI TATAREVIC

'A lot of the decisions on configuration of things… are made from several years of trial and error; kind of brute force working through it in nature'

Cliff Daniels, crew chief at Hendrick Motorsports

The process of assembling a NASCAR Cup Series car has changed in recent years as teams have moved from fabricating their own chassis to using the Dallara-designed, modular Gen 7 platform. Even though they operate in a much smaller box these days, successful teams still find creative ways to make speed. *Racecar* sat down with Cliff Daniels, crew chief at Hendrick Motorsports, to find out how the team builds a car to contest the Daytona 500.

Hendrick is the most successful team in Cup Series history, with over 300 wins and 14 drivers' championships to its credit. It racked up its record-extending 10th Daytona 500 victory in mid-February with William Byron, so the preparations detailed here were evidently worthwhile.

The process of building a fleet of cars for the first race of the 2025 regular season starts almost immediately after the conclusion of the previous campaign. Less than three months separating the chequered flag at Phoenix from transporters being loaded for Daytona means teams need to work extremely efficiently, so schedules for the car builds are laid out in early December before any holiday season breaks.

Hendrick fielded four cars at Daytona for Byron, Kyle Larson, Chase Elliott and Alex Bowman, so it needed to build four primary cars, along with two back-ups to have available in case of damage during practice.

Upon return from Phoenix, all of the cars that raced were measured using the team's in-shop version of the Hawk-Eye OSS (optical scanning station). The data was entered into the team's database, so it could see how components had changed during the race. Cars were also scanned with Hexagon Absolute measuring arms and CMMs (coordinate measuring machines) as they were torn down.

Every component, whether it is a spec part or otherwise, is weighed, measured and checked before and after use, with all the information stored in the team's inventory database

Once apart, all the parts and pieces were also catalogued in the database, where the information remains available for use with the team's simulation software.

Computer control

The calipers, lasers and strings of old are a rare sight in a NASCAR shop these days with everything instead being computerised. Hendrick's array of equipment from Hexagon alone includes seven CMMs, 33 Absolute arms, 13 scanners and a Leica Absolute Tracker that can fit in a single flight case if necessary. The team has also recently opened a metrology lab that features a Hexagon Tempo robot, which can automatically open drawers to pick out parts and set them to be probed for measurements, which are automatically exported to the parts database.

With information on all parts available in the database, crew chiefs and engineers are able to map out the entire next season of cars so they can understand how to split up their limited number of chassis parts. Today's Cup Series machines are based around a serialised safety cell that carries the chassis number. Each centre section is tracked by NASCAR and can only be replaced with a new one if it is declared decommissioned. Teams typically track where each centre section has been used in the past and, if a specific one has tolerances that are a good match for a specific type of track, it is often re-used for that type of track multiple times.

According to Daniels, the process at Hendrick is to actually work backwards when deciding how they use their seven allocated centre sections across the 38-race season: 'I think as teams look to build their Daytona cars, at least for us anyway, it starts with more than just looking at a particular chassis, or car.

'Basically, within the rule structure now, each individual car number gets seven centre sections allocated to it, and then you get 10 front and rear clips. So, part of the process even before you build the first car is to forecast our projected chassis and clip rotation for the entire season. We start at the end of the year and work backwards from there, which kind of brings you to Daytona.

'That starts in the off season, projecting what are we looking for at each race, centre section and clip wise'

Cliff Daniels

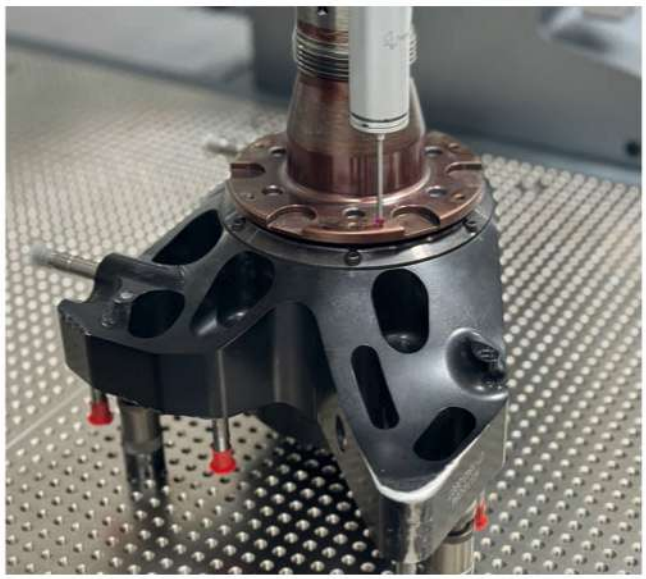
'There are certain characteristics of particular cars we have, or certain clips or centre sections that would make you select one over another per event, per track type, or whatever criteria you may come up with. That process starts in the off season, projecting what are we looking for at each race, centre section and clip wise.'

Virtual assembly

Once a centre section has been assigned for a Daytona 500 car, engineers load up their Daytona car builds from the previous season and start studying them as each car is virtually assembled in their simulation software roughly five weeks before the race.

To do this, engineers access their database of scanned parts and assemble the selection of pieces that best stack up in terms of measurements to conform to what they believe to be the optimal build. Decisions are based on most recent track and tyre data, and any rule changes that may have happened since last season.

After the simulated build is complete, they then analyse it in depth and tweak body and suspension settings to maximise speed, using parts available to them from their database. Around 80 per cent of the parts used to assemble a Gen 7 NASCAR Cup car come from



All parts are built with tolerances and so, while they may look externally similar, subtle differences exist. Detailed measuring allows Hendrick to find the best combination of all those tolerances

single-source suppliers, but all the parts have tolerances and stacking up tenths of a millimetre here and there can result in aerodynamic advantages, or being able to hit an exact number on a specific measurement of suspension geometry.

Next, the build of the car itself. Each car group selects their chosen centre section as the starting point for their car assembly, then the front and rear clips to go along with it. These three major components are assembled and shimmed as necessary for optimal chassis geometry. Only once the team is 100 per cent happy does it release the component to the body department.

There, a similar process is followed whereby the best body panels within the allowed tolerances are selected and attached to the chassis. From there, the car heads to the assembly shop, roughly three weeks before it is set to be loaded on a transporter.

Package deal

During these initial phases, the engineers, and a shop foreman like Hendrick's Austin Konetski, forecasts all the pieces that need to be installed, working alongside specialists from each department. Consequently, once the body and chassis package reach the assembly shop, carts with components like engine, transaxle, suspension and steering sit ready for installation. Finally, the team moves to installing items like brake lines and smaller ancillary components.

Daniels explained to us that selecting every one of these components comes from years of research and keeping a careful and up-to-date parts inventory, along with making the most of the small freedoms teams do have, such as the ability to choose brake pad compounds.

'All of that kind of happens at one time, though a lot of those parts are forecast weeks in advance, using analysis we've done on the inventory we have within all of Hendrick Motorsports. A lot of the decisions on configuration of things, from suspension geometry to our braking scheme, even down to the brake pads we run, steering rack ratios and steering geometry, are made from years of trial and error; kind of brute force working through it in nature.

Stacking up tenths of a millimetre here and there can result in aerodynamic advantages, or being able to hit an exact number on a specific measurement of suspension geometry

'As we're now entering the fourth full-time season of the Gen 7 car, you rely a lot on the notes you've made over the last three seasons, looking back at things you did well and things you didn't, trying to put all that together for how you're going to build the car.'

Once the car is fully assembled, it is measured again, compared to the figures that were projected earlier and tweaked as necessary until the real-world car matches the virtual car as closely as possible. Only then is it sent to be wrapped with the latest livery (all NASCAR Cup Series cars are now vinyl wrapped as the rules do not permit the composite body panels to be painted).

Plating up

The finished car is then rolled over to the step plate area where it is met by a set-up plate crew. At Hendrick, this is a dedicated group that works on all the cars across the organisation, and whose primary task is to make suspension adjustments.

'We have a common structure here at Hendrick, and two set-up plate guys, Cale Johnson and Pete White. They are both very experienced and spend a lot of time changing shims and slugs to get the set-up right for each car. They also have to be proficient with our Hexagon Romer arms and things we use for CMM, so they can go through all the finer details.'

To help fine tune the aforementioned details, the set-up plate crew adjust camber, toe and other suspension variables like bump steer, and load the cars with tungsten ballast where necessary.

As well as finalising suspension geometry, other changes made at this stage including setting the underwing and adjusting the centre floor so it aligns with the diffuser and splitter. Only once all that is done, and all measurements have been verified again, will the car be rolled over the NASCAR Hawk-Eye OSS that Hendrick (and some other leading teams) has installed at its own facility for final verification, prior to arriving at the track. Obviously, if anything does not match with the required data, it is adjusted in the shop.

Parallel process

As the primary car is going through those final stages of preparation, a parallel process is taking place in the various assembly shops as additional cars are built as close to the spec of the primary car as possible. These are the back-up cars that are also transported to Daytona in case the primary ones are damaged in any of the pre-race sessions. A team like Hendrick, which fields four cars in the race, typically build two back-up cars to be shared between all four drivers, and also take a comprehensive package of spares in case there is repairable damage.

Meanwhile, the trucking department is also undertaking a parallel process each time a new car is built as each truck only carries

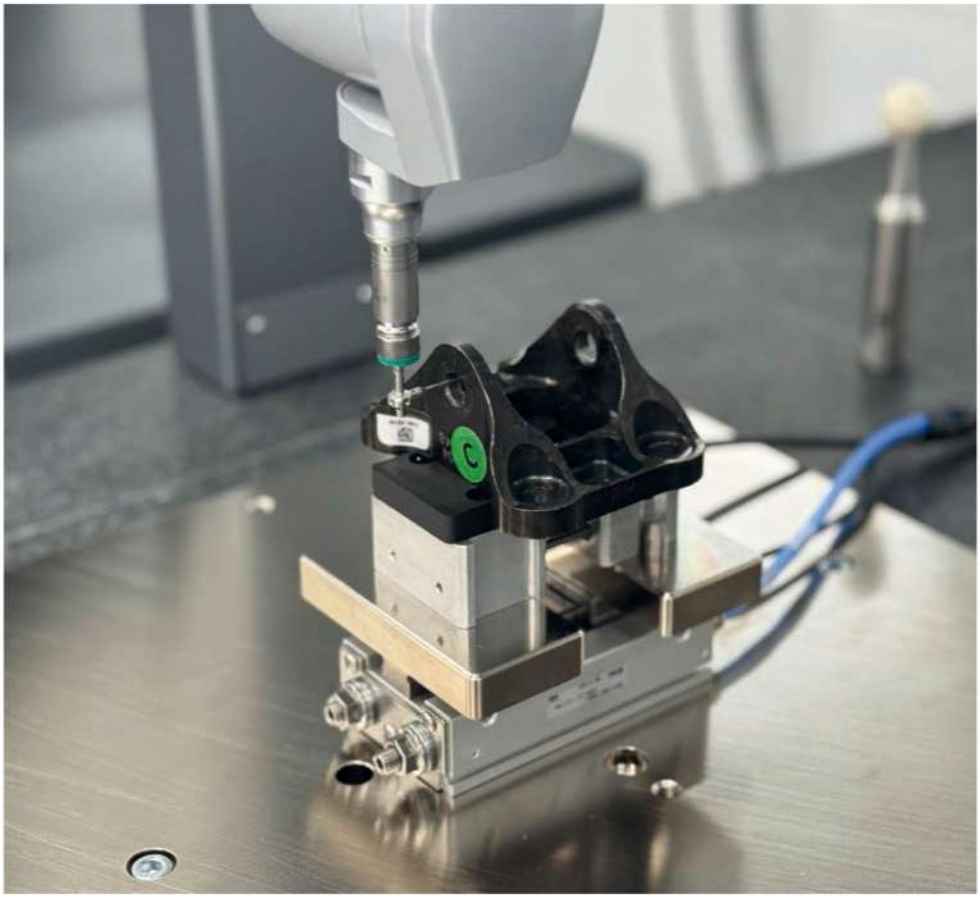
Hexagon Absolute measuring arms are used to assess the cars during strip down, while Hendrick also has a Hexagon Tempo robot that can pick parts and set them to be probed for measurement

spares specific to a single race weekend. For Daytona, that means light duty brake packages, for example, as the heavy duty variants are not used there. Carrying spares that are not used is inefficient.

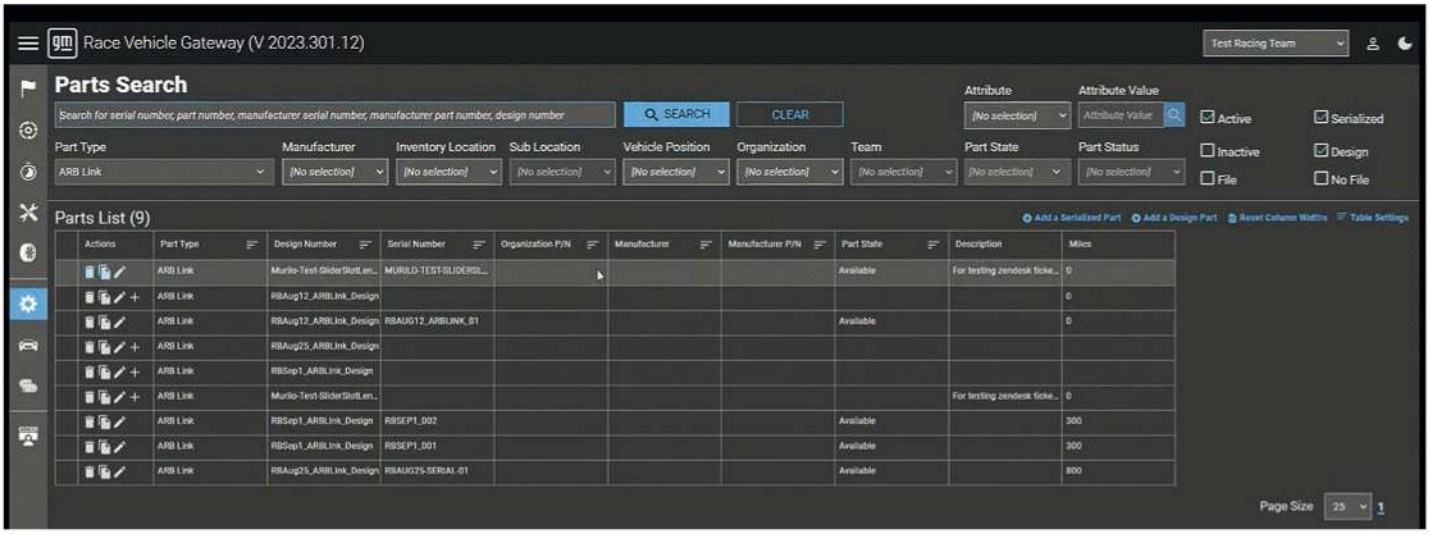
Road crew

The set-up plate crew is then joined by the road crew about a week before the race to familiarise themselves with some of the car's final details. This crew of mechanics is different to those that did the initial assembly work and travels with the car to the track to make any adjustments required during the race weekend. This can be mechanical work, alterations required after technical inspections, or interior adjustments to make the car best fit its driver.

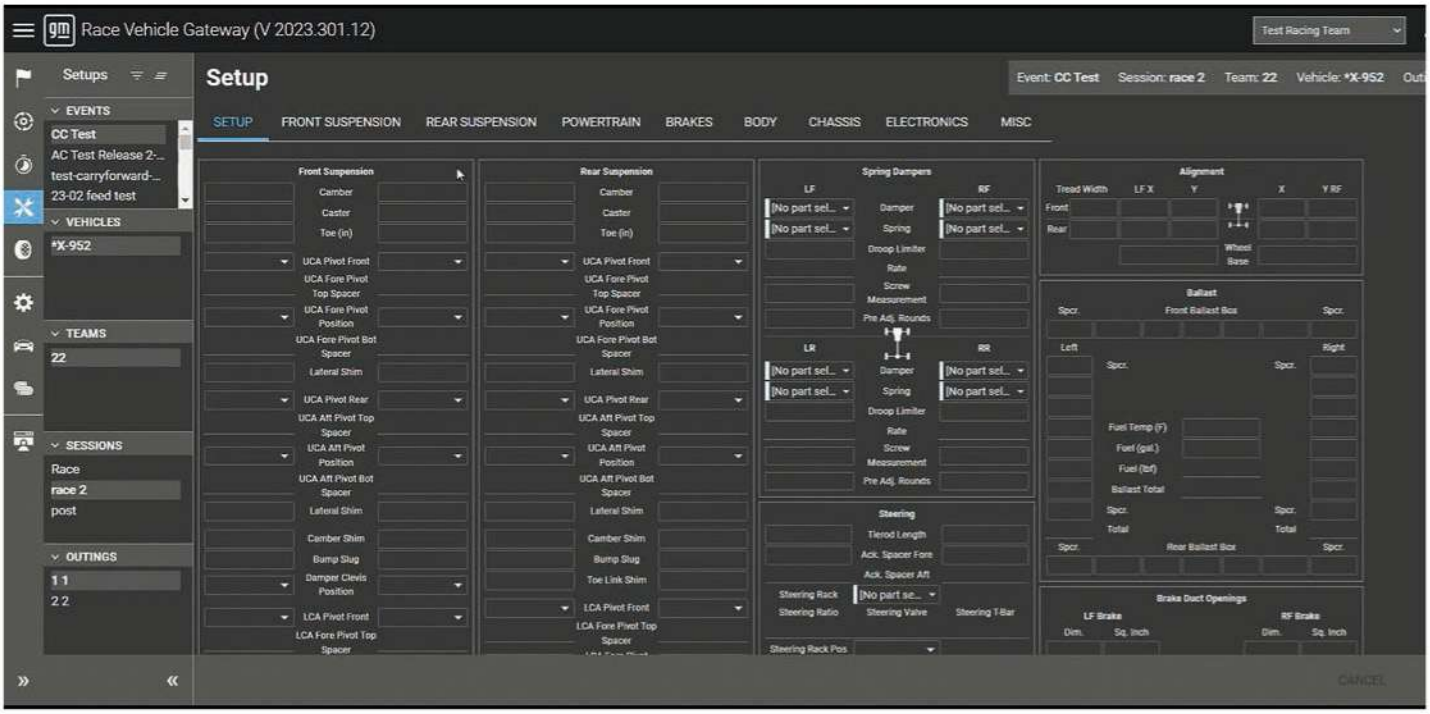
In addition to the road crew, there is also an over-the-wall pit crew whose only job is to perform pit stops and repair any damage. Since the position and droop of the wheels change from track to track, the pit crew walks over from the Hendrick Motorsports athletic training facilities during that final week of assembly to jack the car up and check everything, from how the wheels are positioned in the wheel openings to how low and how quickly they drop with a specific suspension configuration.



All measurements are automatically exported to the team's parts database, which is scoured for best fit parts each time a car is built

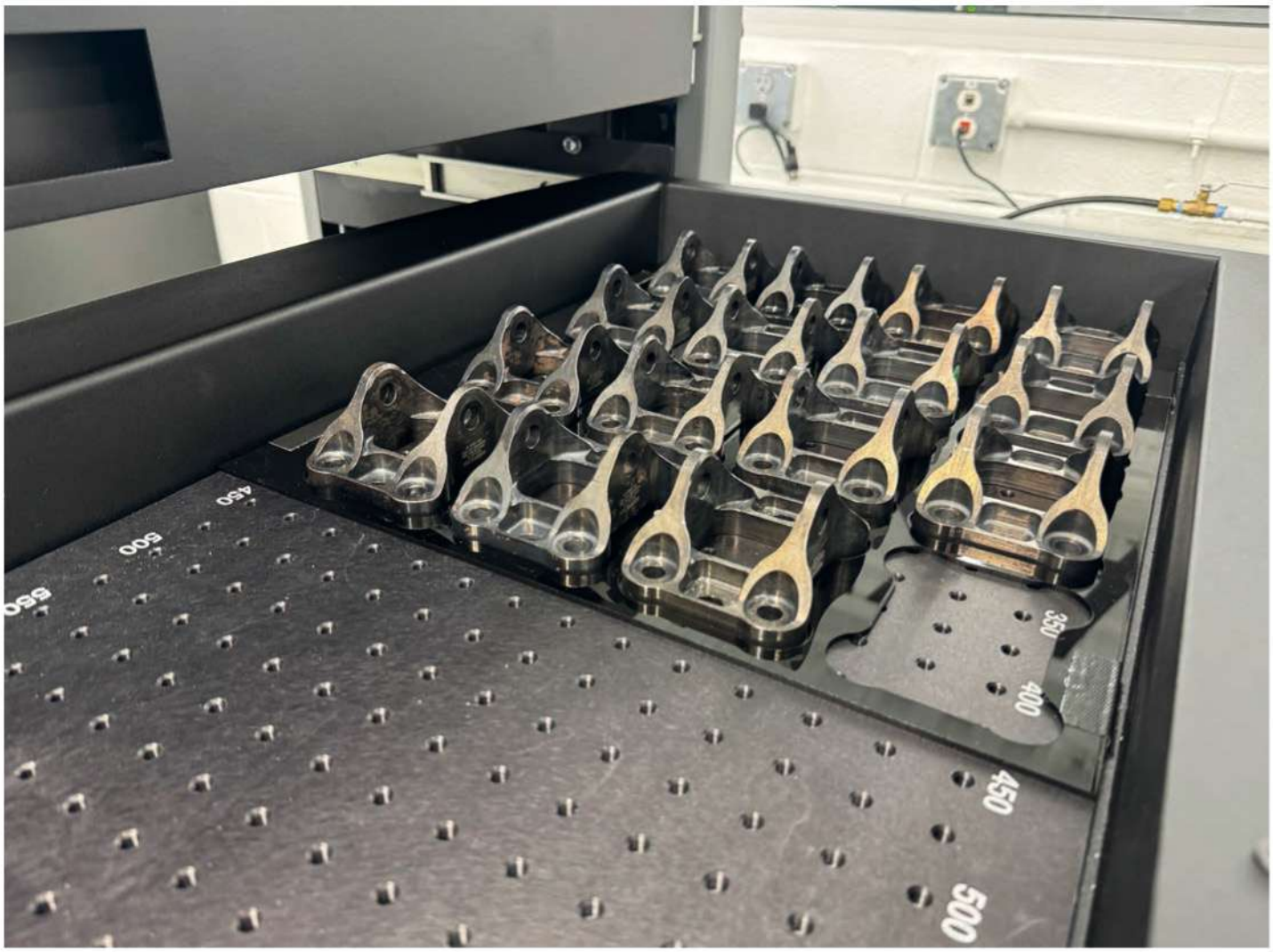


It is not just a case of finding the lightest version of the parts, it's about finding the best combination of parts for a particular chassis going to race at a specific track. Not all NASCARs are equal



The experienced set-up crew will study the data from previous races to find an optimal suspension set-up for the car they are building for a certain race. It must also meet NASCAR's strict criteria

Completed chassis are then transferred to the body shop, where a similar process takes place. All body panels are measured and catalogued and the best ones within the allowed tolerances chosen



You might think this tray of machined components are all the same, but Hendrick Motorsports' database will say otherwise. That's why the team is the most successful in NASCAR Cup Series history

As a final precaution, at Hendrick the car makes one last pass through the OSS before being signed off and loaded.

'The Hawk-Eye is where NASCAR grades us, both on outer body and on wheel alignment,' says Daniels. 'So, while everything I just described comes from our Romer arm set-up reports, at the end of the day you're being graded with the NASCAR wheel alignment system, in conjunction with the Hawk-Eye system. To be absolutely sure, we always run through several wheel alignments on our cars to make sure we'll be within spec when we unload. It's the same for the bodies. We do a surface scan on the Romer arms, which is kind of our own QC [quality control], but the Hawk-Eye is the great equaliser for everyone when you get to the racetrack. That's when NASCAR grades whether you're in or out of spec.'

Understandably, great emphasis is placed on those wheel alignment numbers because failing technical inspection more than once can start a process of multiple penalties, ranging from crew members being ejected from the track to the car being moved to the back of the grid for the race. That cannot be allowed to happen.

'It's an iterative process, which brings us to the very up-to-date build spec we'll be delivering to the track'

Cliff Daniels

This comprehensive process isn't just for Daytona either. As one check list is nearing completion, another is started for the next race. To put that into context, the team was preparing for the race at Las Vegas Motor Speedway four weeks after the 500.

Constant cycle

'As well as preparing for Daytona, we've been working on our Las Vegas build, and for that we'll go through all our notes from everyone at Hendrick, from both races at Las Vegas in 2024, look at our race simulations, our qualifying sims and backtrack it to how the car was built, and how it then evolved from the original build,' explains Daniels. 'There were some rule changes over the winter too, so we have to anticipate the impact of those.

'It's an iterative process, which brings us to the very up-to-date build spec we'll be delivering to the track.'

With that, the four primary cars and two back-up cars are loaded into their transporters, along with their individual toolboxes and other supporting equipment ready for the 800km drive from Charlotte, North Carolina to Daytona Beach.

Due to NASCAR roster limitations, only a handful of personnel joins the car at the track, but a whole group stays connected from the Team Operations Centre (TOC) at the Hendrick Motorsports campus, directly networked into the pit boxes and radio systems. The TOC is typically staffed with vehicle dynamics and performance engineers, along with some team-specific engineers that can go back to those earlier simulations and make any adaptations necessary based on feedback and data they see from the track. All this information is logged into the database and referenced in next season's preparations.

So, even though the team had plenty to celebrate when William Byron crossed the line to take his second consecutive Daytona 500 victory, and put Hendrick into double digits, the iterative process keeps rolling on.

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Racecar *revisits Matt Stone Racing to see how the Australian Supercars team is preparing for its most challenging season to date*

By DEJAN NINIC

Stone glass window

The 2024 season was a broadly successful one for Matt Stone Racing (MSR) in the Australian Supercars Championship. With two wins added to its tally, MSR finished seventh in the teams' standings, an improvement from 10th place the year before.

In *RE* V34N2, we visited MSR to witness first hand how a team approaches the jewel in the Supercars crown, the Bathurst 1000. MSR has competed at Bathurst once more since then, earning a second consecutive top 10 finish with one of its Chevrolet Camaros. However, for all its greatness, Bathurst is just one stop on the 13-round championship schedule, which stretches from February to the end of November. Consequently, preparing for the full campaign represents a totally different challenge to suiting up for one very particular endurance race, with its own strategic nuances.

Preparation for MSR's 2025 season commenced as soon as the previous one ended in mid-November. This included the complete build of a third car for selected Wildcard rounds, a re-build of the damaged no.4 Chevrolet, recruitment of key staff to bolster the engineering team and making predictions on how the new soft compound tyre would perform.

'We focus on the art of going racing,' says Matt Stone, team owner of MSR, which runs two Camaros full-time for Cameron Hill and Nick Percat. The team is entering its ninth year of competing in Supercars and the Super2 Series, which serves as a feeder to the top championship. Improved results have encouraged new sponsorship and brought in the funding required for further growth on the engineering side.

'We have built a fantastic crew over the years, with only one person leaving last year,' says Stone. 'We are committed to growing the performance of the team as a whole, so have recruited four new team members and are really excited about what we are able to deliver on track.'

Finding performance

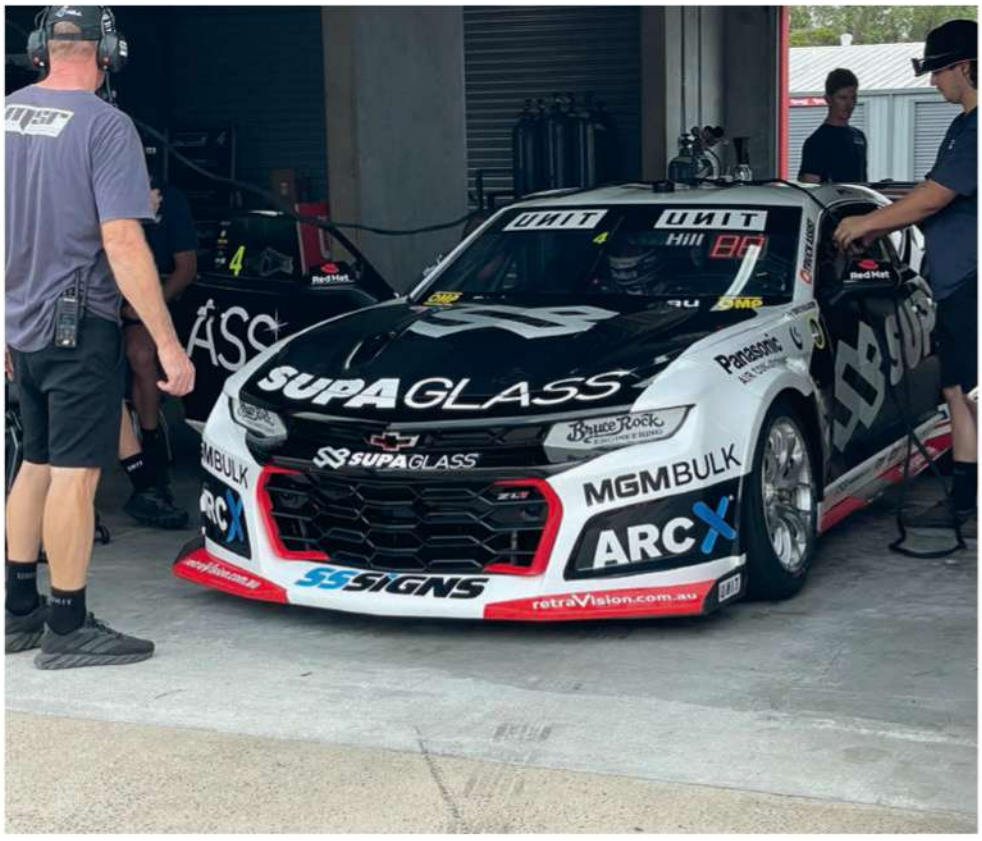
Jack Bellotti, race engineer for Percat, has gone into the 2025 season with optimism. This is because a growing team means the new engineers can take on some of the operational tasks that previously took his attention away from finding performance in the cars and drivers. To this end, MSR has hired two new full-time engineers, Caleb Mutsaerts (race engineer for Hill) and Declan Waller (trainee data engineer). Paul Forgie, the previous race engineer for Percat's car which took both of MSR's wins in 2024, has found new responsibilities internally as technical coordinator, while also initially serving as mentor to Mutsaerts.

The no.4 car had to be completely rebuilt after Cameron Hill took a major tumble at the 2024 season finale in Adelaide. It is shown here during pre-season shakedown testing at Queensland Raceway

Meanwhile, the two existing data engineers, Rohan Kalisch and Oliver Boone, have been given increased responsibility for digging deeper into pit stop data. Boone explains: 'Supercars races can be won or lost in the pits. It's critical for drivers to drive as fast as they can into pit lane, slow down to the exact pit lane speed limit – not one or two km/h below it – and then perfectly hit their mark in the pit box.

'Tyre changes can take as little as four seconds; we even monitor when the fuel coupler is engaged, and how long it takes the air jacks to extend or retract. The data we've gathered from many years of racing is used to train the pit stop team. In the off-season, and between races, MSR practices pit stops twice a day.'

While team members can perfect their skills in data analysis or tyre changing, during the off-season, drivers do not have the same luxury and must find their own means to stay sharp. The Supercars regulations limit track testing to just two days per year, and in 2025 every team had to reserve one of those for the official pre-season outing at Sydney Motorsport Park on 19 February. Percat likes to stay busy by preparing karts for his own



After completing a successful 60km test with Hill back behind the wheel, the car was declared ready to re-enter competition

team and keeps fit by driving them. Hill also uses karting to work on his reflexes. 'Last summer, I brushed off the shifter kart and shared one with [Cameron] Crick at the local track,' says Hill, who is in his third Supercars season. 'Shifter karts put a lot of stress on the body, but the awareness and reaction time are very similar, so it's good training.'

What's on for Crick

Crick is the third driver at MSR and, in 2025, is competing as the Wildcard entry in the team's third Chevrolet. Alongside the shifter kart training, he prepared for the first round at Sydney with a driving simulator, which also offered him time in advance to work with his new race engineer.

The Wildcard entry in Supercars allows each team to enter a third car for the two enduros, The Bend 500 and the Bathurst 1000, plus one additional round beforehand to give the driver more experience. There have been discussions between the teams and Supercars to add a fourth round for the Wildcard, which would also serve as a single round for the additional driver in each enduro pairing.

In 2025, only MSR and Tickford Racing have taken up the Wildcard option. Whilst it is intended to offer further experience and opportunity to young drivers from Super2, MSR looked elsewhere and gave a rising star from New Zealand, 2023 Lamborghini Super Trofeo Europe champion, Brendon Leitch, the opportunity to sample the Camaro at the pre-season test.

MSR started building its third chassis for the current Gen 3 regulations during the 2024 season and, as the necessary parts became available from suppliers, the car slowly came together. It eventually went to Percat, and the existing, race-winning chassis became the 2025 Wildcard car. Pre-season pressure mounted further with the decision to run the Wildcard at the first round of the season at Sydney, due to it being Crick's home round.

Cameron Crick (centre) and his engineer used the off-season to work together on driving technique on the simulator

Shake and service

Meanwhile, the fabrication department was kept busy rebuilding the no.4 Chevrolet after Hill's big crash at the 2024 season finale in Adelaide. The rebuilt car completed a successful 60km shakedown at Queensland Raceway with Hill at the controls, the team reporting just one minor sensor issue. It attributed its successful track return down to intense attention to detail in the servicing of the sub-assemblies.

[The] successful return to track [of car no.4] is most likely down to intense attention to detail in the servicing of the sub-assemblies

Crick drives the no.35 Camaro, shown here at Sydney Motorsport Park. Track testing in Australian Supercars is limited to two days, one of which must be at the official pre-season outing at Sydney

The pre-season test at Sydney (Hill shown) gave MSR, and all the other teams, an opportunity to collate further data on the mandatory new Dunlop soft compound tyres used in the series

Responsibility for sub-assembly at MSR falls to Jason McDermott. 'At the end of a season, almost every part of the car is serviced,' he explains. 'The engines, steering rack and dampers are serviced externally, as required by the regulations, but we service the rest in-house. This includes the Xtrac transaxle, uprights, brake calipers, starter motors, all the suspension arms and then all the non-performance components in the cabin and around the car.

'The cars are completely stripped and rebuilt. Some brake lines and parts of the loom are also replaced, and we also had to fit and plumb the new Tickford Racing steering racks.'

An existing boom and rattle guns also required attention in preparation for the Wildcard entry.

While servicing of the dampers is performed externally by a common supplier, the race engineers at MSR test every damper on their shock dynamometer. Firstly, they are tested for functional performance, including friction and seal drag, and then they are tested at higher speeds to check for any degradation. As the units have external adjustments in both compression and extension, they also have to be matched. This involves adjusting the damper settings and re-testing until the measured resistance meets the same output required by the engineer.

Cool running

One of the few areas in which teams can make developments under the Gen 3 regulations is with regards to the driver cooling system. The rules mandate one be used, but it can either be via forced air or a liquid-cooled vest. Whichever is chosen, it must create an interior temperature lower than the ambient air around the car. Any air entering the car must pass through a carbon monoxide filter. The system is optional in some circumstances, and can be replaced with ballast, but becomes mandatory if the ambient air temperature is forecast to be greater than 32.9degC on race day.

Considering onboard refrigeration systems draw as much as 25A and can weigh up to 8kg, including hoses and ducts, some teams are using dry ice as the cooling medium, but the refrigeration units are

Hill talks through car set-up and test strategy with his race engineer prior to heading out on track in his rebuilt car

'At the end of a season, almost every part of the car is serviced. The engines, steering rack and dampers are serviced externally, as required by the regulations, but we service the rest in-house'

Jason McDermott, sub-assembly engineer at Matt Stone Racing

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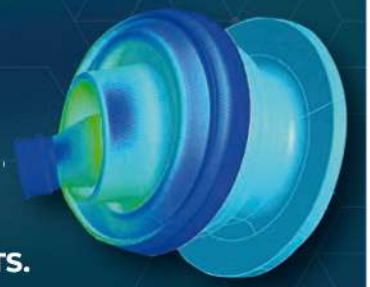

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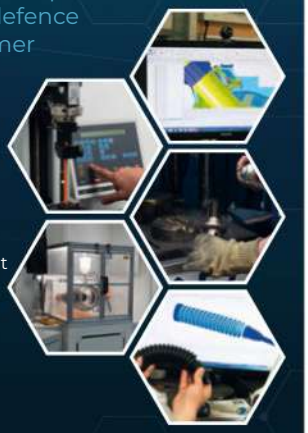

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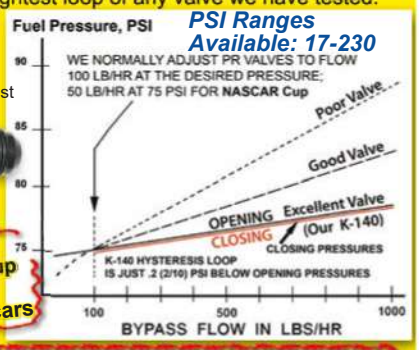

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The most important agenda for the MSR race engineers this pre-season was the impact of Dunlop's new soft tyre compound

Jack Bellotti, race engineer for Percat (left), Declan Waller, trainee data engineer (middle) and Caleb Mutsaerts, race engineer for Hill, at the data station

becoming more popular as they eliminate the need to replenish a cooling medium during longer races. Bellotti has made a significant investment into the new cooling system MSR is using in 2025, but is keeping his design a secret for now.

New tyres please

The most important agenda for the MSR race engineers ahead of the season was the impact of Dunlop's new soft tyre compound. Supercars had intended to introduce a more durable and higher-grip soft tyre to allow drivers to race harder for longer, but degradation is a key factor for strategy calculations in races. Even with refuelling taking place, the undercut can be powerful and, while testing of the new compound during 2024 showed significant improvements in tyre life, they were balanced by reduced degradation at some low tyre wear tracks, where lap time is more sensitive to car mass than tyre grip.

As part of their considering of strategies for each round of the 2025 season, Bellotti and his team worked extensively on the new tyre during the Sydney test. Having one extra car on track paid dividends there.

With only two months between seasons, a successful start to the new campaign always depends on the quality of each team's preparation. For MSR, the addition of a third car for the curtain raiser made life more complicated, but its groundwork eased the challenge. Percat achieved a best result for the team of 12th in race one of the Sydney triple header. Hill was 13th on two occasions, while Crick's best finish was 18th. It was a modest start to the season, but one that MSR feels it can build on using its growing Supercars experience and an engineering team that is being invested in.

Nick Percat wheels the no.10 car. This is the third Gen 3 chassis the MSR team built during 2024, and the combination secured the best result for the team at the 2025 season opener in Sydney

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Flushed with success

How research and motorsport are converging on an innovative way of making hydrogen fuel from waste water

By DANIEL LLOYD

The team consists of University of Warwick researchers and students, all of whom work on the project in addition to their full-time roles

Waste2Race aims to highlight the possibilities of producing hydrogen and building components from sustainably-sourced materials

Where does the water go after we flush the loo, or have a shower? Most of us give it no thought because such mundane, daily actions are taken care of by a complex sewerage infrastructure. Literally, out of sight, out of mind. In basic terms, waste water is funnelled via pipes to a treatment plant where contaminants are removed. The treated effluent is then returned to the water cycle, usually deposited into rivers.

But what if flushing the loo could also be the catalyst for generating fuel for power? Maybe even the kind that could be used to run a racecar. A team from Warwick Manufacturing Group (WMG), the University of Warwick's research arm for collaboration with wider industry, is investigating just that potential. Its students and researchers are building a sports prototype that will operate on hydrogen derived from treated sewage. Their target is to have the demonstrator car running on track later in 2025. The project is called Waste2Race, and is intended to showcase new ways of producing energy and using materials more sustainably.

Organic matter

The conversion of organic waste matter into hydrogen fuel is achieved through a microbial electrolysis cell (MEC). This process has been developed by Wastewater Fuels, a company aiming to commercialise it for both on-grid and off-grid applications. It is currently undergoing trials with Severn Trent, a UK water company that supplies eight million people, including parts of Motorsport Valley.

Despite being called Waste2Race, the hydrogen prototype is essentially a mobile science experiment. The aim is to conduct demonstration runs and perhaps a land speed record bid. WMG and Wastewater Fuels hope this will appeal to motorsport's fan base.

The roots of Waste2Race can be traced to the late 2000s when researchers and students from WMG built an innovative Formula 3 car using sustainable materials. Think steering wheels made of fibres containing vegetable waste and a flax fibre seat incorporating soybean oil. Major news outlets, including the BBC and the *New York Times* picked up on it, running stories on the 'chocolate-powered' racecar, which ended up scaling the Goodwood Festival of Speed hillclimb. More accurately, the fuel it used consisted of processed biomass derived from waste chocolate and vegetable oil.

'It was a high-impact method of developing sustainability research,' says Dr James Meredith, chief engineer at WMG. 'That car happened in 2009. A decade later, we wanted to build another sustainable racing car, but we weren't sure what it was going to be. A number of strands of research were going on at the time at Warwick. Whether it was sustainable materials, recycled carbon fibre or a PhD that was running around microbial electrolysis cells, trying to find a lower-cost substrate.'

The last of those piqued Meredith's interest, and that of his WMG project colleague, Kerry Kirwan, as it could leverage the recent popularity of hydrogen as a sustainable vehicle fuel option. Additionally, the High Value Manufacturing Catapult, a non-profit organisation providing R&D facilities to institutions with commercial interests such as WMG, is keen on hydrogen solutions as part of an industry-wide decarbonisation push.

'Its plan was more for static power and heavy goods vehicles,' notes Meredith. 'We weren't trying to change that strategy, we wanted to demonstrate that you can obtain green hydrogen from, essentially, human waste, and that it gives a very sustainable fuel.

'We wanted to demonstrate that you can obtain green hydrogen from, essentially, human waste, and that it gives a very sustainable fuel'

Dr James Meredith, chief engineer at Warwick Manufacturing Group

WMG

Prof Kerry Kirwan (left) and Dr James Meredith (right) developed the WorldFirst F3, which ran on processed biomass from waste chocolate and vegetable oil. They are now pushing new sustainability boundaries with Waste2Race

We have been trying to take bits of sustainability research we've been doing and apply them to this racecar.'

WMG's initial capital for Waste2Race has come from the Research England Regional Innovation Fund.

Operational issues

It's difficult to imagine how flushing a toilet can help to run a racecar, so let's clear the waters by explaining how the process works.

First, though, some background. Dr Daniel Carlotta-Jones is an expert in waste water treatment, and is leading the development of MECs for Waste2Race. After an undergraduate degree in biochemistry, he embarked on a doctorate at WMG to study MECs and the barriers to their widespread application, with support from Severn Trent.

'The MEC is a technology that can really revolutionise waste water treatment because it's able to treat waste water and produce hydrogen gas as a renewable energy source,' says Carlotta-Jones. 'On paper, it sounds amazing, but the reality is most people doing this are building MECs of a certain size in the lab.' (Carlotta-Jones holds up a pencil pot to illustrate the size he's referring to).

'As soon as they take it out of the lab and start testing it in sewage, there tend to be operational problems, and the results tend not to be too brilliant. One of the biggest barriers is cost. The catalysts you need include platinum and very expensive membranes. If you're going to make an MEC that can treat millions of people's worth of sewage, it's going to be a very expensive bit of kit.'

Therefore, one of Carlotta-Jones' missions has been to make it cheaper to run the MEC on a large enough scale to be commercially viable.

'I found a way of doing it using a recycled carbon fibre material,' he continues. 'It effectively reduced the cost of the system by about 75-80 per cent. There were other things to deal with in terms of capital costs and performance, but it really opened the door to make it a reality.'

After completing his doctorate in 2019, Carlotta-Jones took a job with Severn Trent as an engineer, designing waste water treatment assets for sewage works. He was then approached to set up a company that would commercialise the fruits of his research. Wastewater Fuels was established in late 2021, with support from venture capital and the UK government's Defence and Security Accelerator (DASA) initiative.

'We've taken the technology from prototype lab scale, all the way up to assets that can work with sewage, still with more scope to develop,' says Carlotta-Jones. 'So, when Kerry [Kirwan, deputy pro-vice chancellor of research at WMG] asked us to get involved in the Waste2Race project, we jumped at the opportunity.'

How it works

In basic terms, an MEC is a set of stainless steel mesh rods submerged in waste water. Clinging to each rod are microbes that consume organic matter in the water. The consumed matter is converted into hydrogen ions, which diffuse into the rod and are further processed into hydrogen gas or liquid. That hydrogen can then be transported as fuel, while the leftover water is released into the environment.

The microbes are a type called electrogenic microorganisms, and their growth on the rods is stimulated by an electrical charge.

'The good thing is the microbes we want are naturally occurring in the environment, in waste water, mud and swamps,' says Carlotta-Jones. 'So we're not having to genetically modify, or generate specific organisms, in the lab. We apply a process, and the ones that enjoy living in this process survive. The others don't. We're basically playing Darwin. We're saying there's going to be low voltage, no oxygen and lots of organic carbon to eat. [That determines] the ones that are going to proliferate.'

Electrogenic microorganisms possess the ability to transfer electrons from one source to another. In the MEC, they take electrons within the organic matter of the waste water and metabolise. According to Wastewater Fuels, the MEC process is circular and creates more energy than it consumes.

'When you take an electron from a compound or molecule, you are basically breaking [that molecule],' says Carlotta-Jones. 'Because electrons are used to make bonds, the bond they are breaking is one that is connected to a hydrogen ion. That ion leaves the organic molecule and is reacted with an electron at the cathode and turned into hydrogen. What's amazing is that the electron the microorganisms have taken away from the molecule is spat out onto the anode on which they are growing. It then goes around in a circuit, back to the cathode. To make the process work, you just supply a little bit of voltage.'

The waste water used for the MEC process may come from different sources. Crucially, the amount of hydrogen extracted from it depends on the organic concentration within it. Domestic waste water, for example, tends to enter a treatment works in a more dilute state than waste water from industry, such as factories, farms and breweries. Based on Wastewater Fuels' analysis of average daily energy consumption, it would take 21 humans to produce as much waste energy as a single cow does. So, while human waste can generate enough hydrogen to power a racecar, but you need an awful lot of it.

'From the perspective of hydrogen supply for motorsport, I'm confident we could supply enough to make an impact,' says Carlotta-Jones. 'There is a lot of interest in this sort of thing because the water sector is looking to decarbonise its HGV fleet. It's interesting for them because they can think about making their own hydrogen on-site.

'This project could be a real way to demonstrate the concept of making hydrogen from sewage and running a vehicle with it. Okay, at the moment it's a racecar, not an HGV, but it's still an internal combustion engine.'

Applied technology

To pique the interest of the wider world in Wastewater Fuels' technology, the Waste2Race team needed somewhere interesting to apply it. Its search for an appropriate host vehicle started in late 2023, and eventually settled on the Ginetta 58, a track day prototype from 2018 that was developed out of the British manufacturer's first LMP3 car.

'We are very keen to support UK manufacturing in this,' says Meredith, 'and we wanted something high impact that would look obviously like a racecar. There are some great guys up at Ginetta and, after various chats, we discovered they had a load of parts sat in the workshop that were never going to go on a car.'

It all sounds a bit *Scrapheap Challenge*, but that suited the WMG team nicely as it could build an almost complete racecar for a fraction of the cost of buying a new one.

'For any parts that were missing, we tried to make those using sustainable materials such as natural fibres or out-of-life prepreg,' Meredith adds. 'The steering wheel, for example, is 100 per cent bio-based material, with lots of flax and polylactide, polymer onsets with wood inserts. We've been trying to use as much bio-based material as possible.'

For this, WMG reunited with an old partner from its F3 project, CelluComp, which manufactures components using cellulose fibres recovered from waste vegetables.

'Last time, we used carrot fibre to make a steering wheel. This time around, we've used waste beetroot to make a wing mirror,' highlights Meredith. 'The process is similar, in that once the waste vegetables have been crushed, you end up with cellulose pulp, which can be utilised into reinforced polymers.'

Under the skin

The Waste2Race is a form of hybrid. While the hydrogen fuel feeds the internal combustion engine, an electric motor in each front wheel recovers braking energy, providing up to 103kW (138bhp) of boost on acceleration. Protean Electric, which is working with WMG on other research projects about recycling, supplied the motors. Rather than being tailored to racing, they are of HGV specification. A Bosch Electronic Brake System (EBS) manages the recuperation of braking energy. The battery was initially going to come from a crashed road car, but it turned out to be too bulky, so WMG built its own module from Molicel P45-B cells that were going spare from a different project. WMG hopes the use of electric motors on Waste2Race to stimulate other strands of research related to end-of-life material extraction and re-use.

Sustained power comes from a supercharged 3.7-litre Ford V6, rather than the 6.2-litre Chevrolet V8 that gives the standard Ginetta G58 an output of 575bhp. The Ford unit comes from a Revolution 500 EVO sports prototype. Power is transmitted to the wheels through a six-speed sequential transaxle from Xtrac.

Duravit AG

The MEC process can generate hydrogen from a variety of wastewater sources, from bathrooms…

…to agriculture…

…and even brewing

'The good thing is the microbes we want are naturally occurring in the environment… so we're not having to genetically modify, or generate specific organisms, in the lab'

Dr Daniel Carlotta-Jones, lead MEC developer for Waste2Race

The hydrogen combustion powertrain of the Waste2Race is a method favoured by other recent Le Mans-style demonstrator cars from Alpine and Toyota. The alternative is to use a fuel cell stack to convert hydrogen into electrical energy that runs an electric motor.

'We explored the possibility of a fuel cell and putting an e-motor drive on the rear,' says Meredith, 'but decided to retain the existing gearbox and rear suspension. Essentially, by using a shorter engine, we can create a little extra space for the hydrogen fuel system.'

Storage capacity

The Ginetta's 105-litre fuel tank will be swapped for a dedicated hydrogen storage system. WMG has chosen to store its hydrogen in gas form due to the spatial and financial challenges of keeping the element on board as a liquid, which requires a cryogenic tank set at -253degC.

The amount of hydrogen the Waste2Race car will carry is yet to be defined. The team hopes 5kg will be attainable, though it has the luxury of not being tied to technical regulations that stipulate a certain amount. For context, the latest hydrogen fuel cell demonstrator from the Mission H24 project is targeting 11-14kg to complete the equivalent of a stint at the 24 Hours of Le Mans.

'We've got a large, square space behind the driver,' explains Meredith. 'At the moment, there are really only cylinders available, but a company in the US has quite an innovative hydrogen storage in microtubes that can be formed into any shape you like. We would much rather go for something innovative as it means we can use the space better without undertaking significant modifications.'

The engine will be both direct and port injected, to ensure enough hydrogen enters each cylinder. How the injection will be managed, and how the cooling system will be laid out, are yet to be finalised. What has been determined is an increase in the pressure at which the hydrogen will be stored. WMG originally intended to do so at 350bar.

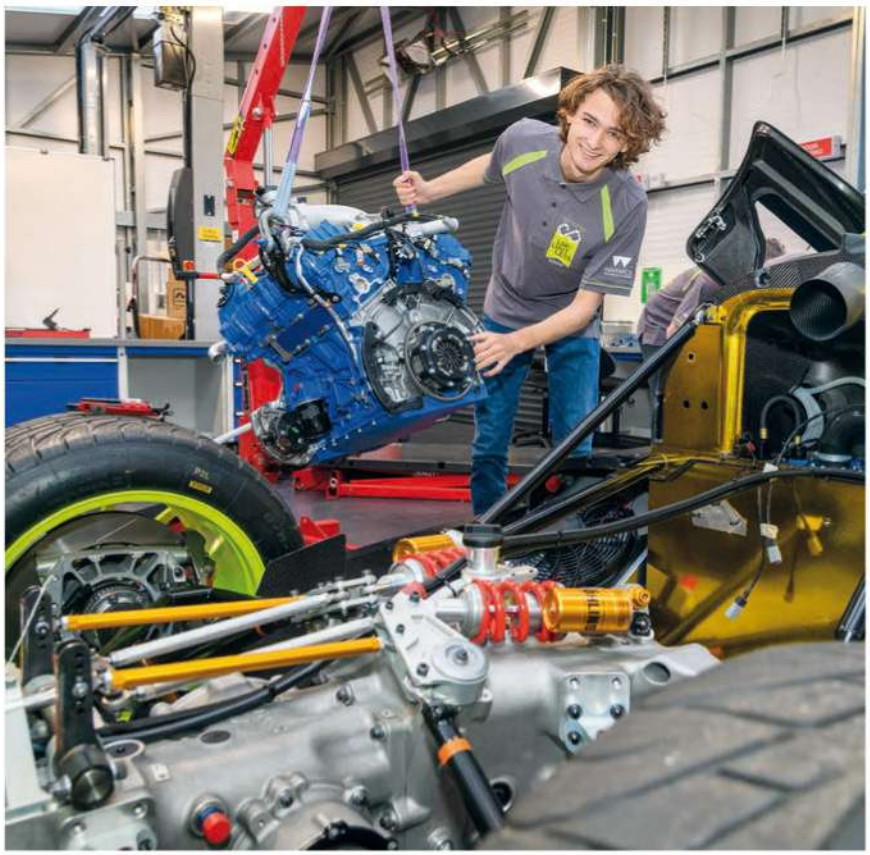
'That was our base level, but there are certain drawbacks in terms of storage capacity, which are going to push us to 700bar,' adds Meredith. 'We wanted to push the boundaries of storage. I have looked to see if there is anything clever in hydrides that can store hydrogen, but nothing is available off the shelf yet. I'm hoping this project will pioneer new research projects and avenues that we can focus on in the future.'

A major challenge to overcome in the approaching months will be understanding how to compress, store and fill the hydrogen that Wastewater Fuels is set to deliver, particularly in terms of safely handling the gas. The UK has a very limited hydrogen refuelling infrastructure, let alone for an experimentally produced version of the fuel.

Track target

When Waste2Race was announced in October 2024, the stated aim was to break 'hydrogen speed records' without further elaboration. In truth, the team hasn't yet defined what measurable challenge it will target. Simply proving the sewage-to-fuel process can be applied to a function (in this case, a racecar that works) will be a major achievement. It's then down to the team, and its budget, to explore how far it can push the car's performance to create more headlines.

FIA land speed records are a complicated business. Within the hydrogen division, there are different records depending on the type of powertrain, such as hybrid combustion, fuel cell and turbine. Inside those categories, there are records for different weight classes, so there are more opportunities to break records than it may initially appear. It is hard to say where the Waste2Race might fit into the criteria, though, because so much is still undefined. Meredith's expectation is for the car to weigh around 200kg more than the Ginetta G58, which stands at 900kg.



The Ford V6 engine being hoisted into the car. Next step will be to define the hydrogen storage infrastructure

'We wanted to push the boundaries of [hydrogen] storage… I'm hoping this project will pioneer new research projects and avenues that we can focus on in the future'

Dr James Meredith, chief engineer at WMG

However, the FIA land speed record for hybrid hydrogen combustion between 1000-1500kg is a whopping 253.994km/h (set by a Hyundai Ioniq Hybrid in 2016). A dedicated weight-saving programme might therefore open the door for a more achievable record. It's all speculation at present, though, as the car needs to be finished and tested first. WMG has a stake in the National Automotive Innovation Centre on Warwick's campus (alongside Jaguar Land Rover and Tata) where it hopes to undergo dyno testing.

'If we get the hydrogen calibration of the engine and the motors all working well, we should have around 750bhp,' says Meredith, 'though that might not be enough to go for a high-speed record. It might be more related to a specific use of sustainable fuel; perhaps a hillclimb attempt or something. It'll be a sensible record that we think we can have a go at. How we frame it and phrase it will get more specific nearer the time.'

For now, WMG is finalising the build of various components, plus the integration of the hydrogen and its associated control and cooling systems. It is also trying to raise awareness of the project to attract the attention of companies that might be able to help. Collaboration is seen as a key to success for Waste2Race, especially when it doesn't have a full-time engineering team. The students and researchers are all doing it out of passion, fitting the work around their study and research schedules.

The MEC is not being touted as a way of producing hydrogen for racing specifically. Wastewater Fuels believes it can be a solution for a wide range of needs. Nonetheless, motorsport plays a crucial role in demonstrating the technology, as well as WMG's various threads of research on sustainable materials. To many racecar engineers, there is little beyond making the car go faster, but, through its dual status as an innovator and a form of entertainment, motorsport also has the capability to support scientific progress. If Wastewater Fuels' sewage-to-energy method takes off as a sustainable hydrogen fuel source, motorsport could claim to be a core reason for its success.

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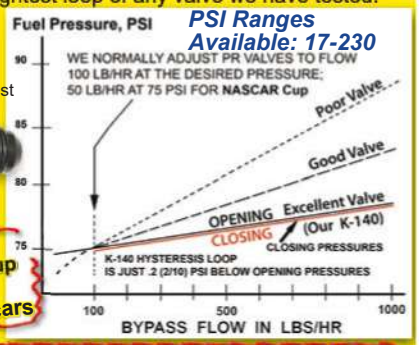

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Teenage kicks

We talk to the people behind the now-delayed TOCA Junior series to find out what it takes to design and build a racecar for drivers as young as 14

By MIKE BRESLIN / PICTURES: ELIZABETH JAY, BRESMEDIA

The Chevron B1417 has been designed specifically for 14 to 17-year-old drivers, and the plan is to run it in an all-new TOCA Junior series that will support the well-established British Touring Car Championship

When the TOCA governing body started its search for a replacement for the Ginetta Junior Championship, which left the British Touring Car Championship's (BTCC) support package two seasons ago, three things stood high on its list of requirements. First, the new series should provide the frantic action that made the Ginettas so popular with spectators. Second, the car should be a recognisable touring car-style shape. Third, it should be designed from the ground up to suit drivers as young as 14 who might become future BTCC stars.

The concept that fulfilled this brief best was the Chevron B1417. The 'B' is a nod to the traditional naming convention of the revived Chevron marque (see box out on p44), and '1417' denotes the 14-17 age range of drivers classed as Juniors. The series in which the new vehicle will race will be called TOCA Junior.

Dave Beecroft is the man behind both the car and the series. A stalwart of the British racing scene, Beecroft began his motorsport career at the age of 17, having switched from a job in a garage to work as an engineer in the British Formula 1 Championship with Cobra Motorsport in the early 1980s.

Since then, he has been involved in many categories, including running a Lexus IS200 in the BTCC in the mid-2000s. For the last decade or so, has been mainly overseeing the Junior Saloon Car Championship (JSCC), so has plenty of experience with drivers at the beginning of their careers.

The plan was for the new TOCA Junior to appear on the BTCC race card at all 10 of its 2025 meetings but, late in February, the decision was taken to delay the Junior series until 2026, as take up of the new car was slower than had been anticipated.

Viewing figures

'TOCA has been missing the Juniors,' says Beecroft. 'As Alan [Gow, BTCC chief executive] has said, it's an important part of the package. There's a lot of talk that TV isn't the thing any more because it's all digital, it's all streaming, but that's not true. Touring cars on a Sunday afternoon still gets massive viewing figures. The biggest figures are for touring car races, but the next biggest used to be the Juniors.'

While the new TOCA Junior series will almost certainly provide entertaining racing when it gets off the ground – give a teenager a racecar and action is pretty much guaranteed – the car is a very different beast to the Ginetta that went before it, or the Citroën Saxo that is raced in JSCC.

'The Saxo's great for kids, for learning, but it's a shopping car trying to be a racing car,' Beecroft says. 'This is a proper racecar. We don't have the compromises you have with a road car trying to be one.'

This means the Chevron B1417 has been designed from the ground up, on a clean sheet of paper, there were still some aspects that came as part of a brief from TOCA: 'The objective, from Alan's point of view, was to go rear-wheel drive, because kids come out of junior racing and go straight into F4. There are already front-wheel drive championships for juniors, with the Fiestas [BRSCC Fiesta Junior Championship] and the JSCC cars. When it comes to the packaging of how you build a rear-wheel drive or a front-wheel drive car, it didn't really make any difference for us.'

This is because the chassis is a spaceframe, so any drive format could be made to fit. Maintaining the link with the BTCC, chassis are built by Custom Cages, the company responsible for the chassis / rollcage work for many cars on the BTCC grid. The 'cage in the Chevron is built to the new 2025 FIA regulations, which means the main roll hoop is a whopping 61mm in diameter.

Touring philosophy

Chassis philosophy is also very much based on the BTCC. 'The idea was to emulate a modern touring car as much as possible, so you have separate front and rear subframes,' says Patrick Scharfegger, production / technical manager at TOCA Junior. 'In the event of an accident, you don't have to put the car on a jig to try and straighten chassis legs, you just unbolt the front subframe, bolt a new one on and attach your engine and wishbones to that. The main cell remains intact, and that's significantly stronger than the subframes, so the subframes act as a crumple zone as well.'

The front subframe supports the engine, gearbox and suspension, the rear one the suspension at the back and the differential. While this will surely cut down on repair bills, the main point is the survival cell aspect. Because while all racing is safety focused today, junior racing needs to be even more so.

'It's a bizarre thing, but parents will let their kids go around on a tea tray at 70mph,' says Beecroft, referring to karting, where the majority of TOCA Junior drivers will step up from, 'but then they look at a racecar and start going on about safety. It's funny, we'll open the door of the car and parents lean in, grab the roll hoop and tug on it to test it, thinking it's going to break or something.'

The car originally came out at around 580kg, but that was deemed to be a bit too light, so it will be a little heavier when raced. That will be achieved by modifying the modular, glass-reinforced polymer (GRP) bodywork. Again, that means individual pieces can be replaced in the event of damage, rather than needing a new shell.

Driver position

The location of the driver within the car has also been the subject of much thought. 'The driver is sat right inside the roll hoop structure,' explains Beecroft. 'We have used a lot of touring car stuff in this. The seat is touring car-spec, six-point mounted, and it stays still. The pedals, steering and gear lever all adjust to the driver. That means the central mass of the driver stays in the same position.

'One of the things with the Saxos – and the Fiestas are the same – is if you've got a small kid in one, they're right up against the steering wheel, and it's the pedals, really, that dictates this. Whereas in the Chevron, the driver's sat well back, so marshals and safety crew can easily get in. They can access the driver, and the doors are on pins, so they come off easily if there's an incident.'

The chassis is a chunky spaceframe with integral rollcage built by Custom Cages to FIA 2025 regulations

BTCC-spec seat is fixed in place, but pedals and steering wheel positions can be adjusted to suit individual drivers

As well as plenty of space in the cabin, there is also a big glass area on the car, which makes it easier for marshals to see inside, and for the drivers to see what's happening around them. This has the added benefit that TV viewers and spectators can see the drivers at work. Incidentally, it's not just the driver that's been considered here, because junior racing is all about learning, so the interior has been designed with room for an extra seat for driver coaches on track days.

Another safety feature is a system that addresses a common issue across racing, but perhaps one that is particularly relevant when you have a grid full of drivers who are not so experienced in operating clutches.

'You've got your rain light on the back, and the ECU is programmed to detect a stall,' says Scharfegger, who also runs a team in JSCC.

'The idea was to emulate a modern touring car as much as possible, so you have separate front and rear subframes'

Patrick Scharfegger, production / technical manager at TOCA Junior

'As the stall is occurring, and the revs drop below a certain rpm, the light starts flashing. Also, the mapping has a level of anti-stall, so it'll adjust the ignition timing a little to help a driver get off the line.'

Regarding electronics, there's a hi-tech Haltech dash, while the looms are similar to those used in the BTCC. 'Some connectors on a touring car loom will be a higher spec, but the rest is very similar,' confirms Scharfegger.

The rear wing on the Chevron is another item shared with the BTCC. This is adjustable, but will be mainly used for balancing the aero

The car's styling has divided opinion, with some saying it looks like a touring car from the 1990s. That's not necessarily a bad thing

Adjustable rear wing is the same as on the BTCC cars, but in TOCA Junior will mainly be used to balance the car aerodynamically

A touring car-style, bolt-on subframe holds the engine and gearbox, and makes for easy replacement in the event of an accident. Power unit is a Mazda 1.9-litre, inline four that has been de-tuned to 100bhp. Junior cars are limited to 100mph for safety reasons

rather than generating downforce. There will also be a front splitter integrated with the floor (the one seen here is an interim device).

Most of the downforce will be produced by the rear diffuser situated behind a completely flat floor, although it's not expected to be a huge amount, simply because this is not what this racecar is about.

Indeed, part of the challenge of making a racecar for juniors is that outright speed is simply not of the essence. In fact, junior cars are supposed to be engineered so they do not exceed 100mph, for safety reasons. The Chevron B1417 is no exception to this rule, which means the engine has not been so much tuned, as de-tuned.

The power unit in question is the four-cylinder, 1.9-litre, Mazda L 'world engine', and TOCA Junior has bought up a stock of these, which will be sealed and run at 100bhp, down from around 145bhp. This reduction is achieved through the ECU and using an air restrictor, while a thicker head gasket is fitted to reduce compression ratio.

All of this means the power units should have a very long life. 'The engine is so under-stressed,' says Scharfegger. 'In reality, nobody should even consider having to replace an engine for two years. It doesn't even need a major service. It should be a low-maintenance engine.'

Shift work

The gearbox should also be low maintenance, as it's out of a Mazda RX-8. Elite Racing Transmissions has worked on the internals of the unit, as well as supplying a limited slip differential, also based on the one used in the Mazda. As to any worries that an LSD might result in power-on understeer with inexperienced drivers, Beecroft says: 'We spent some time working with the guys at Elite, and what they're giving us worked straight out of the box.'

That's borne out by comments made by 2022 BTCC champion, Tom Ingram, who tested the car at Pembrey in late 2024: 'As a base car, it is very strong, very neutral. It's fun and easy to drive. You can get to the limit comfortably and it's also quite forgiving. Importantly, it's confidence inspiring, which, for the young guys and girls that are going to be driving it, is a really big plus point.'

Those young racers will, however, have to get used to something rather alien in the world of modern racecars: a traditional, H-pattern gearshift. The presence of this has raised eyebrows in some quarters, but there are a few good reasons for using it.

'When you teach a kid to use an H-pattern gearbox, they can drive anything,' says Beecroft. 'If they've driven a sequential [first], getting them to drive an H-pattern is very difficult. People say, "Oh, but they're never going to drive an H-pattern gearbox again,"

Note the body roll evident in this shot. The car is deliberately run with soft spring rates to help young drivers learn about and understand the effect of weight transfer across the chassis

Tom Ingram, the 2022 BTCC champion, tested the Chevron at Pembrey late last year, finding the rear-wheel drive car fun, easy to drive and very forgiving

All the suspension parts and the brakes are Chevron branded, having been designed by the TOCA Junior team and then outsourced for manufacture

but they will, because they'll go to Goodwood to drive somebody's Lotus Cortina, or Cobra [as many BTCC stars do].

'Also, a lot of the teams didn't want sequential,' Beecroft adds. 'I'd say it was a 50 / 50 split between the teams wanting a sequential and those who preferred an H-pattern. H-pattern is more user friendly, more serviceable and it's cheaper.

'We could easily put a sequential 'box in the car, and we could put paddles on the car too, that isn't a problem. It just costs the best part of 10 grand more.'

School 'box

A further benefit is that learning to use an H-pattern gearbox means gaining a more thorough understanding of what the car is doing under the driver, which is really the point of TOCA Junior. This is, after all, a school – just more fun than the ones we attended. With this in mind, the suspension will be set up so drivers can learn about and understand the importance of weight transfer.

'It's about teaching them,' Beecroft says. 'We can set the car up however we want, so we will be limiting spring rates because we want some movement in the car. It's easier for the kids to feel it if there's movement.'

There is still enough adjustability that drivers can learn about getting the car right for a particular track, or day. 'They can adjust anti-roll bars front and rear,' Beecroft confirms. 'We'll also have a range of spring rates, and the dampers are adjustable, as is the camber.'

Suspension is wishbone front and rear, rose jointed throughout. All the suspension components, including dampers, are branded as Chevron, as the team at TOCA Junior designed the system, which was then produced bespoke for the car. The same goes for the brakes, which can be adjusted via a brake bias mechanism.

Meanwhile, like the BTCC, TOCA Junior will use Goodyear rubber, with restrictions placed on the number of tyres allocated for each event, to help ensure parity and limit costs.

'They can adjust anti-roll bars front and rear. We'll also have a range of spring rates, and the dampers are adjustable, as is the camber'

Dave Beecroft

'It is an all-weather tyre,' says Beecroft of the Direzza product the Chevron will use. 'We've used it on our Saxos for the last six years and it's used in lots of other championships. It's great. There was talk of us running a wet tyre but, for us, an all-weather tyre just makes sense, because if it starts to rain in the assembly area, they can still go out. If they're going to start changing tyres, it messes the TV schedule up for the [BTCC] touring cars, which is important.'

Saloon styling

Also important in a one-make championship is the aesthetics of the car, and there has been much comment on this since the Chevron's launch in the summer of 2024. Much of it was positive, but not all. The thinking when it came to styling is that TOCA Junior always wanted to go with a three-box 'saloon' format, not least because of the front and rear subframes that made it difficult to create a silhouette version of an existing road car.

'The issue you've got these days is nobody produces a saloon car, as they used to, in the three-box style,' says Beecroft. 'They're all very much coupé-like. And if they're not like that, you're into an SUV-type thing. The traditional saloon car has gradually gone.'

Beauty is, of course, in the eye of the beholder, but the B1417 certainly looks more like a touring car than the sports-style Ginetta.

QUICK SPEC: Chevron B1417 TOCA Junior

Chassis
Steel spaceframe built to FIA 2025 regulations, with bolt-on front and rear subframes; GRP bodywork

Engine
Mazda L series, four-cylinder, 1.9-litre sealed unit, de-tuned to 100bhp

Suspension
Chevron-branded package with wishbones front and rear; adjustable dampers; anti-roll bars front and back

Aero
BTCC-spec rear wing; flat floor with rear diffuser; front splitter integrated into floor

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Making a marque

Dave Beecroft acquired the Chevron name, including the rights and trademark, from the former owner of Brands Hatch, Nicola Foulston, in 2022. However, he has had a link to the historic manufacturer for much longer, having grown up near its base in Bolton, Lancashire.

'I used to hang around the yard when I was a kid,' he remembers, 'and while I could never afford to own a Chevron, I found I could own the company name.'

Chevron was founded by gifted engineer and amateur racing driver, Derek Bennett, in 1965, building cars for the Clubmans category to begin with, before going on to make a number of successful sports racers, including the Chevron B8 and B16, and rapid single seaters for F3, F2 and F5000. Bennett was in the process of designing a Formula 1 car, the B41, before he was killed in a hang-gliding accident in 1978. The car went on to compete in the British Formula 1 Championship, with Tiff Needell's second place at Zolder in 1979 being a rare highlight.

While the B41 was not successful, the firm's B24 F5000 car did put one over decent F1 opposition at the 1973 Race of Champions at Brands Hatch, when Peter Gethin beat the grand prix runners to win a race that was open to both formulae.

Chevron continued in several guises after Bennett's death, but not without legal struggles over the rights to the brand. A plethora of national and club level Chevron cars were produced by one of the companies in the 1980s, including Sports 2000 prototypes and single seaters. There was then little activity, bar a couple of IMSA cars, until the early 2010s when a separate entity launched the Chevron GR8, which raced in the British GT Championship. That business was then sold to Foulston and Ian Cox's historics team, WDK Motorsport, in 2016. When WDK folded shortly after, its Chevron mantle was passed on to Beecroft.

Chevron was famous for both sportscars and single seaters. The car in the foreground is its B37, a one-off F5000 built in 1976 that was based on the B35 F2 car

It also exhibits an impressive level of engineering and attention to detail, which is important for a car that will race in a high-profile arena like the TOCA package.

Supporting the BTCC is clearly one of the key draws of TOCA Junior, as is the fact it will use a bespoke racecar, designed for juniors from the off. But no purpose-built racecar comes cheap these days, especially one which contains so much motorsport-grade steel. That said, these cars are not as expensive as the social media rumour mill has been suggesting.

'We've got this mad rumour going around that the cars are £100,000,' says Beecroft. 'They're not. They're £75,000 (approx. US$93,900). Okay, there's VAT on that [20 per cent in the UK, which brings it to £90,000], but all the current teams are VAT registered, so they can claim that back. People are saying it's an expensive car, but a Formula 4, which is a tub with four corners on it, is £100,000 (approx. $125,200).

Business expense

It's also important to note that this car is aimed squarely at professional teams, although Beecroft does not discount 'dads and lads' becoming involved. As is the way with the race hire business, a team's initial expense should soon be amortised.

'For the teams, it's like buying a Transit van,' says Beecroft. 'It's just a tool you need for the job. If you spread the cost over five years, or even three years, they would write it off in the books, and the car will have a 10-year life.'

At time of writing, one of the teams was quoting a budget of £125,000 (approx. $156,500) for a season, Scharfegger tells us, which is about right for this level of car, and for racing on the TOCA package. According to Beecroft, this level of expenditure should not deter TOCA Junior's target customers: 'If you're coming from top-level karting, people are already spending way more than that.'

The fact the debut of the series has been delayed, at least until 2026, is a dent in the ambition, and leaves a hole in the BTCC package for 2025, but the car is ready to go and the organisation now has more time to attract paying customers. 'We've got 30 chassis kits built,' says Beecroft, 'and the same number of sets of suspension, engines, gearboxes… It's all there.'

'For the teams, it's like buying a Transit van. It's just a tool you need for the job'

Dave Beecroft

The Chevron B1417 is a proper racecar, aimed at professional teams, with most of the drivers expected to move up from top-level karting

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On a knife edge

Small, light, nimble, powerful and reliable, this is the extraordinary world of Polaris side-by-side racers as they compete on the most challenging rally of them all

By LAWRENCE BUTCHER

The SxS class was only introduced to the Dakar Rally in 2017 but has proven to be incredibly popular. Little surprise when you can buy a machne like this for a little over £100,000 and give pretty much everything on the entry card a run for its money. Other benefits incude ease of servicing, reliability and a massive dose of fun

Polaris may have started its journey making snowmobiles, and then utilitarian work vehicles, but it has moved with the times and, when the UTV market took off, it was well positioned to use its knowledge and experience to create market-leading models. It was an obvious step from there to offer a purpose-built competition machine

Everything about the RZR Pro R Factory is hi-spec, as evidenced by the motorsport wiring and onboard electronics

Polaris has a long history of racing, dating back to its snowmobile efforts in the 1960s and '70s

Those paying attention to this year's Dakar Rally will have noticed that, on some stages, the factory-backed cars in the T1 class would be overhauled by pint-sized buggies, tearing past the lumbering beasts as they exploited their greater agility. Those were the SxS class, otherwise known as Side-by-Sides or UTVs (utility terrain vehicles). This is a relatively new addition to the Dakar, introduced in 2017 on the back of an explosion in popularity for such vehicles with both recreational and competition users.

Readers in the United States will be far more familiar with the SxS concept, though it is becoming increasingly common in Europe, providing exceptional off-road performance in a more compact package than a traditional 4x4, with greater useability and capability than a regular quad bike.

Traditional motorcross bike manufacturers such as Honda, Suzuki and Yamaha all produce side-by-sides, but the two undisputable heavy hitters in the market are Canadian company Can-Am and US-based Polaris. The latter could be credited with creating the modern incarnation of the concept.

It might not be a huge name in motorsport, but Polaris has a long history of racing, dating back to its snowmobile efforts in the 1960s and '70s. The company has been building utility vehicles since the 1980s, but it was the introduction of its RZR model in 2007 that switched focus from

Under the minimal skin is a steel spaceframe built by Technique Chassis in South Carolina, the same company that builds Gen 7 chassis for NASCAR. It meets all relevant SFI and FIA safety standards

work-focused machines to performance toys. Overnight, the RZR established Polaris' SxS racing credentials.

With a strong focus on North American races, particularly the SCORE (Southern California Off Road Enthusiasts) Baja series, the latest works incarnation of the RZR Pro R is a consistent front runner, often beating all other vehicles except the top-tier Trophy Trucks. Despite being referred to as 'golf carts' by some of the old timers, SxSs are not to be underestimated.

Works effort

Following years of success with its works teams, Polaris has now taken the decision to offer its customers a purpose-built competition model, the RZR Pro R Factory. Alex Scheuerell, director of racing at Polaris, says its customers were already modifying production versions for competition, so the company felt it may as well produce a variant that harnessed its decades of race experience.

'We have something special with the Pro R,' he says. 'We have invested millions in the platform, and we wanted to authentically show people why it's the best. No one knows this machine better than we do. We have a factory team in California and Sébastien Loeb Racing in France. We are developing these machines anyway, so we might as well sell them.'

Although only small, the RZR packs a lot into a tiny footprint. The chassis is a tubular frame construction fabricated from high-alloy steel and manufactured by Technique Chassis in South Carolina, the same company that builds for NASCAR's Gen 7 platform. The Pro R Factory uses the same basic construction as the regular production RZR, but with modifications made to meet the relevant FIA and SFI safety standards, and to allow greater adjustment of the suspension. Impressively, the Polaris found room to package a 130l ATL fuel cell, which spans the floor of the driver compartment.

Occupants sit centrally, while at the front unequal length wishbones support coilover shocks. At the rear is a Polaris-developed trailing arm set up that Scheuerell describes as 'a long trailing arm, but one with radius rods to control camber, and a toe link as well.'

The engine is rear mounted, with a transmission sited to its front, sending drive to front and rear locking differentials (there is no centre diff' but a disconnect to provide 2WD is used). Power is provided by an inline, four-cylinder, four-stroke engine of Polaris' own manufacture, connected to a CVT (continually variable transmission).

'The best part about it is the performance in cornering and how you can balance the rear with the front, to make it a very precise handling vehicle'

Alex Scheuerell, director of racing at Polaris

Polaris has designed and developed the latter unit, but it is constructed by transmission specialist, Team Industries, based in Minnesota.

It would be fair to say the suspension is where the magic happens. For a start, there is 22in of travel (over 550mm), less than a Trophy Truck but more than the T1+ cars are permitted at the Dakar.

Secret sauce

'It works really well,' says Scheuerell. 'It's got really good bump compliance, and you can dial in the anti-squat and all that sort of stuff with it. The best part about it is the performance in cornering and how you can balance the rear with the front, to make it a very precise handling vehicle. With that much travel going over big bumps, our secret sauce is making it turn like it's on rails.'

Polaris has worked extensively with Fox over the years on damper development. The American company has a wealth of experience in off-road racing on both four and two wheels, as evidenced in our recent article about the Ford Raptor T1+ (*RE* V34N11), where Fox's dampers excelled in combining compliance with platform control.

'It's a tricky balance between comfort, traction and control,' continues Scheuerell. 'You need to do things differently off-road than on-road, and the technology has evolved in a different way in terms of the tuning and calibration of dampers. Fox and Polaris have pushed each other to improve.

We were really happy to see that Ford went with them. We work with the same guys that work on that programme, and it has been fun to compare notes.'

Of course, the kinematics of such a long-travel suspension system packaged in a small platform are a challenge. Again, this is something Polaris has been steadily refining over the years, as Scheuerell explains: 'It is about considering things like ensuring the halfshafts have minimal plunge throughout the travel, maximising steering angles, all the tricks we have learned developing this platform. It's a challenge, but the way one of these things can go through the gnarliest terrain and hit the biggest bumps will knock your socks off; it just doesn't seem physically possible.'

Powertrain philosophy

Propelling this miniature missile cross country is the ProStar Fury HO 2.0 engine, developed in-house by Polaris. The naturally aspirated motor puts out 255bhp, running to over 8500rpm and is based around the production units found in lower RZR models, as well as the company's Slingshot road vehicles. The RZR engine is optimised for off-road use. For example, the lubrication system is designed to work effectively even at the very steep angles encountered when traversing slopes.

'The way one of these things can go through the gnarliest terrain and hit the biggest bumps will knock your socks off; it just doesn't seem physically possible'

Alex Scheuerell

'We've been developing our 500cc, single-cylinder engines for over a decade now. We kind of just keep adding pistons and cylinders to them. We have a lot of 1000cc twins, which are basically two 500cc singles put together. This is just two more [cylinders] added to the front of that,' says Scheuerell.

Reliability is, of course, key in long off-road rallies, and Scheuerell notes that as the racing Fury is closely related to the production engine (which can be uprated to 225bhp) the team was starting with a proven package. 'It'll go multiple seasons without a rebuild,' he adds confidently.

Some readers may have raised an eyebrow at the mention of using a CVT in a race vehicle. However, they are common in the UTV and snowmobile worlds. Polaris first used one on an ATV in 1985 and sees no reason to change things. The layout is standard for the manufacturer, and the transmission has drive and a driven clutch, connected by a belt. The big advantages a CVT brings are smooth power delivery, and the ability to ensure the engine is always in its powerband.

The transmission is located in front of the engine and power is transferred to locking differentials, Polaris having experimented with centre differentials and decided against their use. 'For our vehicles, with our suspension, the size of our tyres and other factors, it really doesn't need one,' confirms Scheuerell.

Both the engine and transmission are calibrated to provide a broad operating window as conditions the RZR encounters during rallies are certainly varied. They can range from low-speed rock crawling, where winching may be required, to flat out, high-speed desert stages.

'The slow speed, driveability and the ability to have really good compliance and bump projection through your suspension is key,' asserts Scheuerell. 'The chassis and engine must work together because if your wheels are just hitting stuff and bouncing off, you don't have any traction. That is combined with low-speed driveability with the engine calibration and transmissions,

Compared to other Dakar contenders, the Polaris RZR is tiny, but don't let that fool you. It packs a punch and serious off-road capability

so you can do everything from absorb rocks going five miles an hour to hitting whoops at 90 miles an hour.

'Every time I go out on one of these things I'm like, can this survive? Especially the tyres. It's unbelievable the rocks we go through without punctures. To this day, after 16 years of working on this stuff, I still can't quite believe it.'

Engineering muscle

To say these SxsS are put through punishing environments would be a gross understatement. They need to be able to survive the gamut of terrain challenges, from long-distance races such as the Baja 1000 and the Dakar, to the King of the Hammers. For those not aware, the latter is an annual event held in California that combines fast desert stages and extreme rock crawling.

Scheuerell says that keeping vehicles in one piece on these events is simply down to having broken enough parts in the past to know what to reinforce: 'Ferrari didn't just develop their SF-25 [Formula 1 car] in the span of a year, they've been working on it for decades, and every year they get better. Polaris has had the same opportunity. We're the leader, we're the ones always pushing the speed, pushing the technology, but the advantage we have

'The slow speed, driveability and the ability to have really good compliance and bump projection through your suspension is key'

Alex Scheuerell

All components used on the Pro R race version have been tried and tested in a range of demanding environments

With 550mm of travel, and plenty of adjustability, the Fox-developed suspension is arguably the RZR's finest asset

Engine is a Polaris-built, 2.0-litre, inline four that's optimised for off-road use, makes 255bhp and revs to 8500rpm

is all the internal knowledge we've gained along the way, the engineering muscle we've built up over the years.'

As with everything in racing, it is a case of finding the balance between being competitive and being reliable. 'Rule number one is just making it survive, but it's a delicate balance because one of our competitive advantages is keeping things lightweight, too,' says Scheuerell. 'It's about finding those weak points and attacking them, thinking what do we need to go 10mph faster through this, and what do we need to look after on the car?'

It helps that in the case of the RZR, the standard production model is not so far removed from the racer, meaning much of the company's day-to-day R&D also feeds into the motorsport programme.

'We've got the data, and the engineering horsepower to tackle those problems,' adds Scheuerell. 'The race team is a small group, but we work closely with the whole off-road engineering team that has decades of experience making things survive.'

Of course, even with the best engineering, things break. A tussle with an errant boulder, or a poorly judged jump can still tear a corner off. Comparing its approach to serviceability with the FIA World Rally Championship, Scheuerell says, 'I think rally probably does a little bit better job than we do, making things super modular, so it's just a couple of bolts here and there, on and off. I think that's still coming with us.'

Arguably one of the most potent off-road machines money can buy, at least when compared on a pound-for-performance basis

Service with a spanner

However, the types of events the RZR sees tend to be even more remote than in short stage rallying, so serviceability in the middle of nowhere, using just the tools on the car, is paramount. 'There's a lot of things we do in that regard,' explains Scheuerell. 'For example, we try to use the same size head on all the different fasteners, so you just have a single set of wrenches to take a whole corner off, a lot of things like that.'

Given everything that has been said, it may seem surprising that it has taken so long for a company like Polaris to offer a customer race version of its popular RZR, but that is testament to the high calibre of the standard production offerings. It is the logical choice, though, both from a customer demand and brand image perspective.

'You have these teams tearing apart the production RZRs and building what they think a race RZR should be, but they don't have all the learning we have,' explains Scheuerell. 'They don't know all the pains we've been through, or how much development went into some of the components used on these machines. So they end up throwing a bunch of stuff away and putting new stuff on, just to make it worse. That's our advantage. We know where the weak parts are, and we know what's really good, so we don't mess with the good parts, we just tweak the stuff we know can be upgraded a little bit.'

The end result is arguably one of the most potent off-road machines money can buy, at least when compared on a pound-for-performance basis. Polaris says it will only be producing 30 RZR Pro R Factory models a year, which have a retail price of just under $140,000 (approx. £110,000). Not bad at all for a machine that can cause the Dakar's leading T1+ prototypes to look over their shoulder.

With stages often held in remote and hostile environments, a lot of thought has been given to reliability and ease of serviceability. For example, a common head size on all fasteners makes repairs simpler and reduces the size of tool kit carried

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Machine learning is increasingly making its presence felt, but good race strategy still relies on a touch of the human factor

By JAHEE CAMPBELL-BRENNAN

Once upon a time, in the early years of motorsport, success was largely dictated by who had the fastest car. Outright performance was king, and engineering innovation was the primary differentiator. However, as technological advancements escalated, the pursuit of speed became an increasingly expensive game. The rising cost of competitiveness began to erode the sport's accessibility, concentrating success into the hands of manufacturers with deep pockets and gradually edging the privateers out.

The levels of technology reached are great for the engineers working in it, but not necessarily for the health of the competition. The FIA World Endurance Championship's late LMP1 hybrid category stands as a prime example of this unsustainable escalation, with only manufacturers entering and budgets of around €500 million.

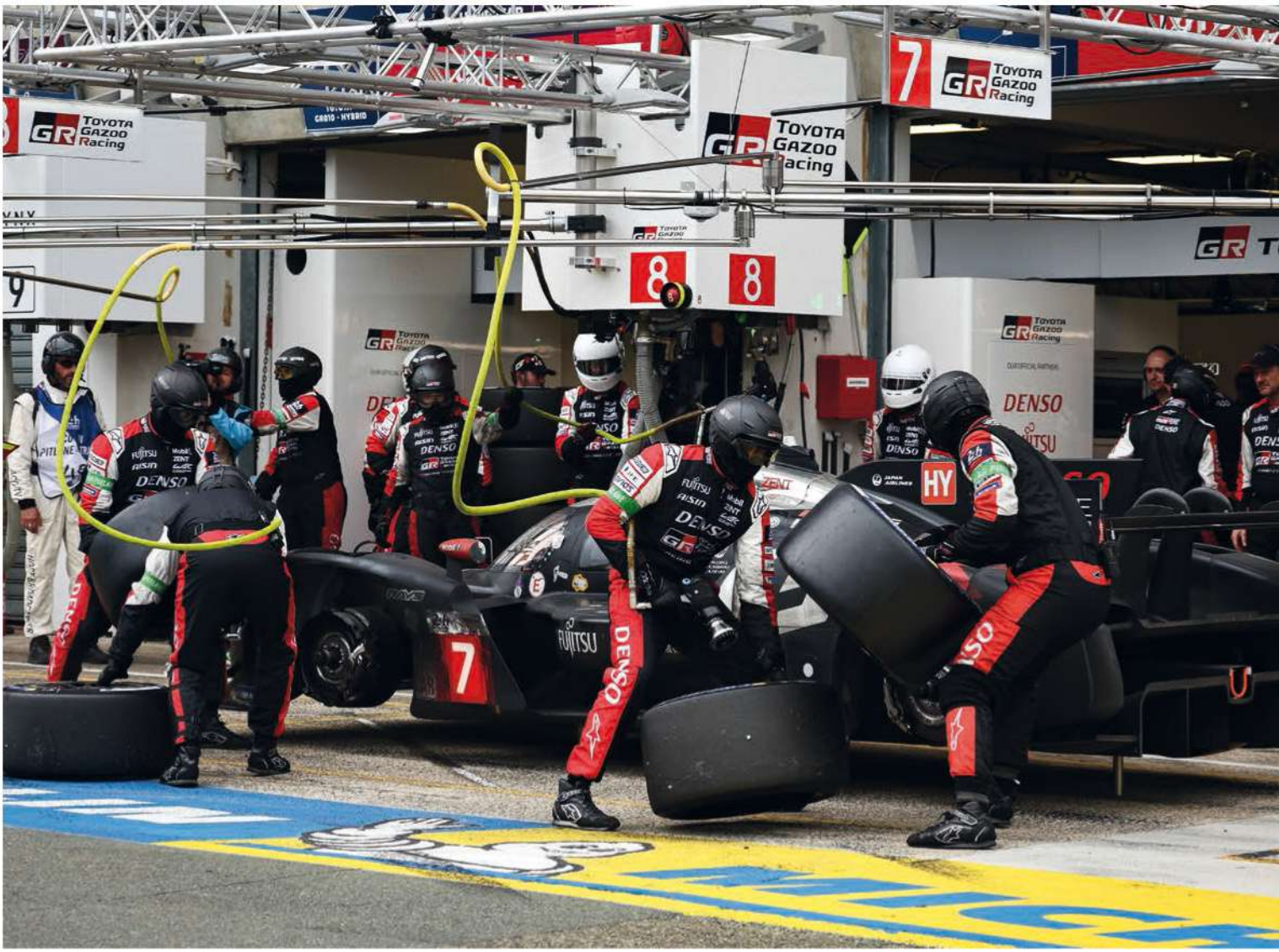
To counteract such runaway costs, modern motorsport introduced stringent regulatory frameworks. We are now familiar with Formula 1's cost cap, while other series rely on homologation and Balance of Performance (BoP) measures to level the playing field.

Once homologated, teams are locked into their car specification, unable to develop, modify or replace components without approval from the championship organisers. Meanwhile, race-by-race BoP adjustments impose constraints on key performance parameters such as ride height, ballast weight and wheel camber to maintain parity.

Yet, if all avenues for competitive advantage were closed, motorsport wouldn't be a sport at all. Hence why today, particularly in sportscars, optimising tyre management and executing an effective race strategy have become critical to success.

Whether in F1, WEC, GT World Challenge or the gruelling 24 Hours of Le Mans, race strategy revolves around making the right tactical decisions at the right time.

Balance of Performance allows cars of all shapes and sizes to compete on an equal footing with each other, but limits on technical development place the emphasis on strategy



Deciding when to stop, or when not to stop, has always been an important decision to make for race engineers in the heat of competition, but in today's motorsport it is a critical factor

Poetically, race strategy is where potential manifests as performance. Outmanoeuvring the competition is a matter of being the most calculated, adaptable and cunning, and generally revolves around the following three main parameters: 1) tyre strategy – when to stop and which tyres to fit; 2) fuel strategy – managing refuelling windows and fuel loads; 3) driver stint management – optimising driver rotation (where applicable) and fatigue levels.

In smaller operations, it can be the race engineer alone analysing the race environment to make these calls, guided by a combination of intuition and experience. In bigger teams, with large budgets and the luxury of strong head counts, strategists and performance engineers have dedicated roles within this decision-making process, and work directly with the race engineer to make these calls using insights produced from data.

Even basic statistical techniques can be remarkably effective here. For example, simple regression models can estimate and predict tyre degradation in terms of lap time drop-off over a stint. Factor in fuel burn effects, and teams can predict the degradation curve of their car's performance with reasonable accuracy.

Using this data, race engineers can piece together an optimal strategy to understand how many pit stops should be made, when to make them and whether fuel should be added when they do.

Sporting regulations in most major championships these days limit the number of tyres available for a race weekend, meaning some pit stops will necessitate fitting used tyres from previous sessions. The approach to managing all these different parameters, and the magnitude of their effect, is critical.

Poetically, race strategy is where potential manifests as performance. Outmanoeuvring the competition is a matter of being the most calculated, adaptable and cunning

For example, in a race where tyre wear is asymmetric, circuits with predominantly right-hand corners, teams may opt to fit new tyres only on the heavily loaded left side, while using worn tyres on the right. This mix of new and used tyres can actually be more beneficial, depending on wear patterns and available sets.

Added complexity

Fuel strategy introduces another layer of complexity. Is it better to minimise fuel load and keep weight low, or run with a fuller tank and align tyre changes with fuel stops? The answer depends on race duration, tyre longevity and pit stop time losses.

There's already a reasonable mental load in gathering and drawing inferences from data required to make just these decisions, and we're yet to even begin to consider race and environmental conditions.

When these factors are optimised, without interference from traffic or external race events, the result is a 'free air strategy', one designed to complete the race in the lowest possible total lap time.

Even with a limited data set from previous races or practice sessions, teams can construct an effective free air strategy with relatively simple, Excel-based modelling. Such techniques allow engineers to estimate optimal stint lengths and pit stop timing with surprising accuracy. This is deterministic modelling, where the same outcome is achieved when given the same input.

Where strategy grows in complexity exponentially is when competitors are introduced into the fray. And they generally are. Suddenly, the optimal race becomes fluid, shaped by the movements, decisions and unpredictable variables introduced by other cars and drivers. It is no longer enough to simply optimise lap time in isolation. Teams must account for track position, race neutralisations, undercuts, overcuts, defensive positioning and the impact of traffic.

From the moment the lights go out, all bets are off. Every overtaking attempt, each defensive manoeuvre and any in-lap or out-lap introduces potential for time loss or forced deviations from the planned strategy.

Timing software

In order to track and manage what one's competitors are doing on track, in-house solutions needed to evolve from spreadsheets and basic programs into sophisticated pieces of professionally developed software.

The main function of any timing software is to receive a live stream of race data, detailing competitor position on track, sector times and speeds, and then present and visualise them in ways that allow engineers to gain powerful insights into how the race is developing in real time. HH Timing software has been around since 2015 and focuses on doing precisely this job.

'When I was a race engineer in the early 2010s, strategy tools were lacking, timing feeds were not as available, and most teams relied on one-person solutions or in-house tools,' says Manu Hugon, co-founder of HH Timing. 'We wanted to create a software that made decision making easier and provided clearer strategy insights. The inspiration for our software came from a need for efficiency.'

In terms of strategy development, understanding pit loss, and predicting where your car will find itself in terms of track position, is a must-have feature of any meaningful software.

If a rival pits earlier than expected, it may force a reactive strategic call, either covering their stop to maintain position or staying out longer to exploit fresher tyres later in the race. To develop on basic timing features and actively generate actionable advice, we jump a level of complexity to probabilistic techniques.

As recently as 2008, F1 teams were using in-house developed tools and Excel spreadsheets to manage strategy trackside

Monte Carlo

In contrast to deterministic methods outlined already, probabilistic models use probability distributions to define an output, which means no two sets of analyses will produce the same outcomes.

Monte Carlo analysis is a probabilistic process that allows multiple scenarios to be assessed simultaneously, enabling teams to identify the statistically optimal strategy based on a range of possible race conditions.

HH Development

HH Timing software collects live timing streams and presents the information in ways engineers can use to make effective strategy calls during races. Ultimately, it all comes down to efficiency

Game theory in action; outwitting Red Bull gave Mercedes the win at the 2021 Spanish Grand Prix

Rather than committing to a single deterministic prediction, as with a free air strategy, this method of analysis performs thousands of simulations, each incorporating random variations in lap times, tyre degradation, pit stop losses and competitor actions. This generates a probability distribution of outcomes, helping engineers determine a strategy most likely to succeed.

'Monte Carlo is mainly used for sensitivity analysis and finding crossover points in strategies,' explains Mike Caulfield, former head of race strategy at Haas F1 team, and current senior product specialist at SBG Sports Software. 'You run through one-stop, two-stop, and three-stop simulations to see where the advantages are. It's fast and provides randomness, but it's only as good as the assumptions you put in.'

Quantifying risk

The real benefit of Monte Carlo analysis lies in its ability to quantify risk and uncertainty. Instead of relying on a single 'best guess', teams can evaluate how different strategies perform under a variety of conditions. This enables real time adaptability if conditions change mid-race, such as unexpected tyre wear or a sudden safety car. Teams can update their input parameters and re-run simulations during the race to determine whether their current strategy remains viable, or if switching things up would be better.

However, probabilistic modelling is still somewhat rigid and, in the environment of a race, can be a bit unwieldy. Since they rely on predefined probability distributions, situations occurring outside of this can be missed, which may lead to poor strategy calls.

A team might base its tyre strategy, for instance, on historical degradation rates but then, if the track cools down unexpectedly, or evolution due to rubbering in too early changes degradation performance, they may find themselves unwittingly pitting too early, giving away a stint advantage.

Monte Carlo tools are still used in a high number of teams, in Formula 1 and otherwise, but they aren't perfect.

True strategy tools need to continuously adapt to real-time race conditions, and incorporate live telemetry, historical trends and competitor behaviour to refine strategic forecasts. This allows teams to react with higher precision, predicting not just how the race will unfold, but also how their competitors are likely to respond.

Take the undercut vs overcut dilemma as an example. If a competitor pits earlier than expected, do you follow suit to defend track position, risking excessive tyre degradation late in the race? Or do you stay out longer, hoping to eventually capitalise on fresher tyres? The choice depends on multiple factors, including tyre warm-up characteristics, traffic, fuel load and, crucially, whether the opposing team *expects* you to react. If they believe you will pit immediately in response to their decision, they may attempt to manipulate your strategy.

Game theory

As strategy becomes increasingly dynamic, every decision influences, and is influenced by, competitor reactions. This is where game theory – the mathematical study of decision making in competitive environments – becomes a very interesting concept.

Game theory is the study of decision making in situations where multiple individuals or teams interact and the outcome for each player depends not just on their own choices, but also on the choices of others. It provides a structured way to analyse strategy calls when teams must act based on incomplete information.

A good example of this is the so-called Prisoner's Dilemma. In a motorsport context, the analogy is of two teams who must make a choice – perhaps whether to pit early or stay out – without knowing what the other will do. If both teams stay out, they may both suffer excessive tyre degradation and lose pace.

As strategy becomes increasingly dynamic, every decision influences, and is influenced by, competitor reactions. This is where game theory… becomes a very interesting concept

Modern motorsport race strategy is not just about the decisions you make for your own drivers, it's about the decisions you can influence your competitors to make, too

If one pits and the other doesn't, the one who pitted might gain an undercut advantage. However, if both pit too early, they both risk unnecessary tyre wear later.

Integrate this approach with probabilistic modelling and things starts to become interesting, developing a matrix of possible strategy options for a competitor and a set of counter actions to neutralise any advantage. So, if the competitor does x, we do y, but if they do y we do z etc. Combined with an objective estimate of the probability of each scenario happening, teams can use this technique to manipulate a race quite effectively.

One exciting example of applied game theory was observed during the 2021 Spanish Grand Prix, when Mercedes forced Red Bull into a defensive position. Strategists at Mercedes realised that if they followed Red Bull's one-stop strategy, their driver, Lewis Hamilton, would finish behind Max Verstappen. Using predictive analysis, they simulated a two-stop alternative, calculating the exact length of the stop lap, and the pace required to make the strategy work. The software helped the team determine when to pit and how much pressure to apply, forcing Red Bull to act defensively. In the final laps, Hamilton closed the gap and overtook Verstappen for the win, executing the strategic plan to perfection.

Deeper analysis

The role of advanced statistical analysis has become increasingly significant as the complexity of race strategy develops. While intuition and experience are still crucial to any strategic calls, software developments have facilitated more comprehensive analysis, preparation and execution of a race weekend.

The transition from static pre-race planning to dynamic probability-based adjustments allowed teams to quantify risk more effectively. But software suites have developed that further to give customers a competitive advantage.

This level of statistical sophistication has allowed teams to fine tune their strategic playbooks beyond what was possible even a decade ago. However, while statistical models provide strong decision making frameworks, they still rely on human interpretation. Engineers must decide which probabilities to act upon, and which require additional contextual evaluation.

SBG's RaceWatch is a well-established race strategy software package, serving as a real-time processing tool that consolidates these models and presents them in a way that trackside engineers can quickly implement.

As recently as the early 2000s, motorsport strategy tools were primitive. This changed with the introduction of tools like RaceWatch, as Caulfield explains: 'RaceWatch first came out in 2008. At that point in the sport, strategy tools were still very basic. There was very little hi-tech, or simulation software. Most of the teams' work was done in high-end graphs or spreadsheets, and there were no live analysis tools. The inspiration behind RaceWatch was to bring everything together, bring in the timing from all competitors and other relevant information.'

Machine learning is a technique in which an algorithm ingests a large amount of data and processes it such that useful trends, correlations and inferences can be drawn in order to make predictions about future events

Any tool that can present relevant data to the engineer to lighten their mental load during a race is a big plus.

'RaceWatch is a tool that can be built up from scratch,' continues Caulfield. 'It's a workbook. We give them the options of what they want, and they can plot it in the best way to provide useability, so they can just focus on the race. You can create a race page, and then you can add a tyre degradation viewer and the pit window on there. You can put however much, or little, information you want on there, depending on the situation.'

Traditional statistical techniques still underpin the software, but the innovation, and the real forward momentum within it, lies in the integration of these methods into a tool to provide the foundations of a data-driven race execution.

Paceteq is another developer making great strides in the space with its One Timing suite. Julien Simon-Chautemps is a former F1 race engineer for Toyota, Renault and Sauber, who is now a strategic advisor for Paceteq, alongside his role as CEO of JSC7 Engineering.

'We are in a scenario where we're calculating thousands of scenarios before the race,' he says, 'and importantly recalculating them during the race with tools such as Monte Carlo analysis, almost in real time as live data streams in, almost in real time to reduce the issue with unpredictability and update the model. That gives you the advantage in terms of the information to make rapid decisions during the race.'

Machine learning

Nevertheless, these statistical techniques can't quite match the dynamic nature of racing. Being so heavily data driven, motorsport is fertile ground to find applications for new technology. Artificial intelligence (AI) and machine learning are words regularly heard in today's tech space, but how is motorsport embracing them?

Machine learning is a technique in which an algorithm ingests a large amount of data and processes it such that useful trends, correlations and inferences can be drawn in order to make predictions about future events. It's still probabilistic, but the input variables are learned from previous data rather than being manually defined. It offers more rigour and mathematical precision than any human team could replicate.

'Machine learning re-calculates based on what's happening during the race, but also based on the previous race, the previous year etc.' says Simon-Chautemps. 'You can put all that into the algorithm that you re-calculate based on historical data and online data, and do hundreds of calculations, thousands of times faster than any human could do.'

With almost 30 pit stops to make, developing a comprehensive plan before and during the race, and then also being adaptable to unforeseen circumstances, is key to success in a 24-hour endurance race such as Le Mans

Teams now develop strategy-predicting algorithms to give further control over their destiny. Combining these with commercial software, and experience, makes a strong package

That sounds fantastic, and in championships with stable regulations and years of history behind them, it could even be the magic bullet. But what happens when a track has been re-surfaced, or as degradation changes? Are all your predictions, and historical data, rendered invalid? And what happens if it rains, but just a little more or less than your reference data, or if track temperature reaches a record high or low?

AI models struggle with externalities such as sudden temperature shifts, tyre degradation anomalies, or unforeseen safety car deployments. Human engineers instinctively adapt to these variables.

This data variability limits the effectiveness of AI models trained on past races. The unpredictable nature of motorsport means AI must handle scenarios it has not encountered before. This reliance on data from a limited number of races can lead to 'overfitting', where the AI model becomes too specific to historical conditions and therefore struggles to generalise to new ones.

'With the strategy side of things, I still think it's very much in its infancy,' says Caulfield. 'Just because for the ability for machine learning to work well, it requires so much data. And when you come to terms with strategy, it's not big data. Every track is an individual component, and every race is an individual. They're all independent in nature.'

Use it wisely

In its current state, then, AI can only serve as a complementary tool to support human strategists, rather than a primary decision maker. The sticking point, really, is quantifying how much its predictions can be trusted.

It offers the potential to process vast amounts of data quicker than humans ever could, but it still requires oversight and interpretation by experienced engineers.

That said, the industry is forging ahead at pace, but with the uncertainty this technology in its infancy justifiably generates, and tightly guarded IP, solutions can sometimes feel like black boxes. Without a thorough understanding of how predictions are made, some of the better resourced teams are generating their own machine learning algorithms. This is where customisable software becomes very useful.

'We developed a plug-in option, which allows our customers to use our software as a base and build whatever they like on top of it,' explains Hugon. 'This allows them to do things like run machine learning systems and other simulations on AWS. The result comes back to HH Timing and integrates with the rest of the package, so you really can take it as far as you want.'

With all these options available, it's never been more important to use a holistic approach, and to see software as a valuable aid, rather than an end-to-end solution.

'Some engineers, especially younger, less experienced ones, can get too immersed in all the tools offered and forget to look out the window to see if it's raining outside. They get so deep into the models and data that they lose sight of what's actually happening in the race,' notes Hugon.

'At the end of the day, there will always be a free space for human input on the pit wall. Decisions are based on data, smart common sense and experience'

Julien Simon-Chautemps, CEO at JSC7 Engineering and strategic advisor to Paceteq

Simon-Chautemps continues this sentiment: 'At the end of the day, there will always be a free space for human input on the pit wall. Decisions are based on data, smart common sense and experience. That's why, if you take F1 as an example, there's a clear pattern. Some teams are really good at strategy, some are not. It's not because one team is 'smarter' than another, it's about how well they merge their tools they have available with human intuition.'

Building trust

As AI matures and teams refine their models with more diverse and representative data, its flexibility and dynamicism will develop. Trust will then build, and its role in race strategy will grow. For now, though, the use of AI remains limited and experimental, highlighting the continued importance of human expertise and real-time adaptability.

That said, the days of making gut-feel strategy calls are over. Motorsport has transitioned from an era where instinct and experience ruled, to one where data and predictive models define race outcomes.

In terms of the future, there's seemingly boundless scope for augmenting engineers to make decisions during a race, as Simon-Chautemps postulates: 'I feel the future will be AI completely. We're talking about fully integrated simulation with quantum computing, running millions of calculations beyond what we can do on current computers. Maybe even augmented reality tools that help engineers visualise strategies in real time without typing a single command.'

In a sport that is characterised by emotion, the fallible nature of humans adds undeniable excitement, intrigue and unpredictability. Automation is on the increase and, in the end, winning isn't just about driving faster, but about thinking faster.

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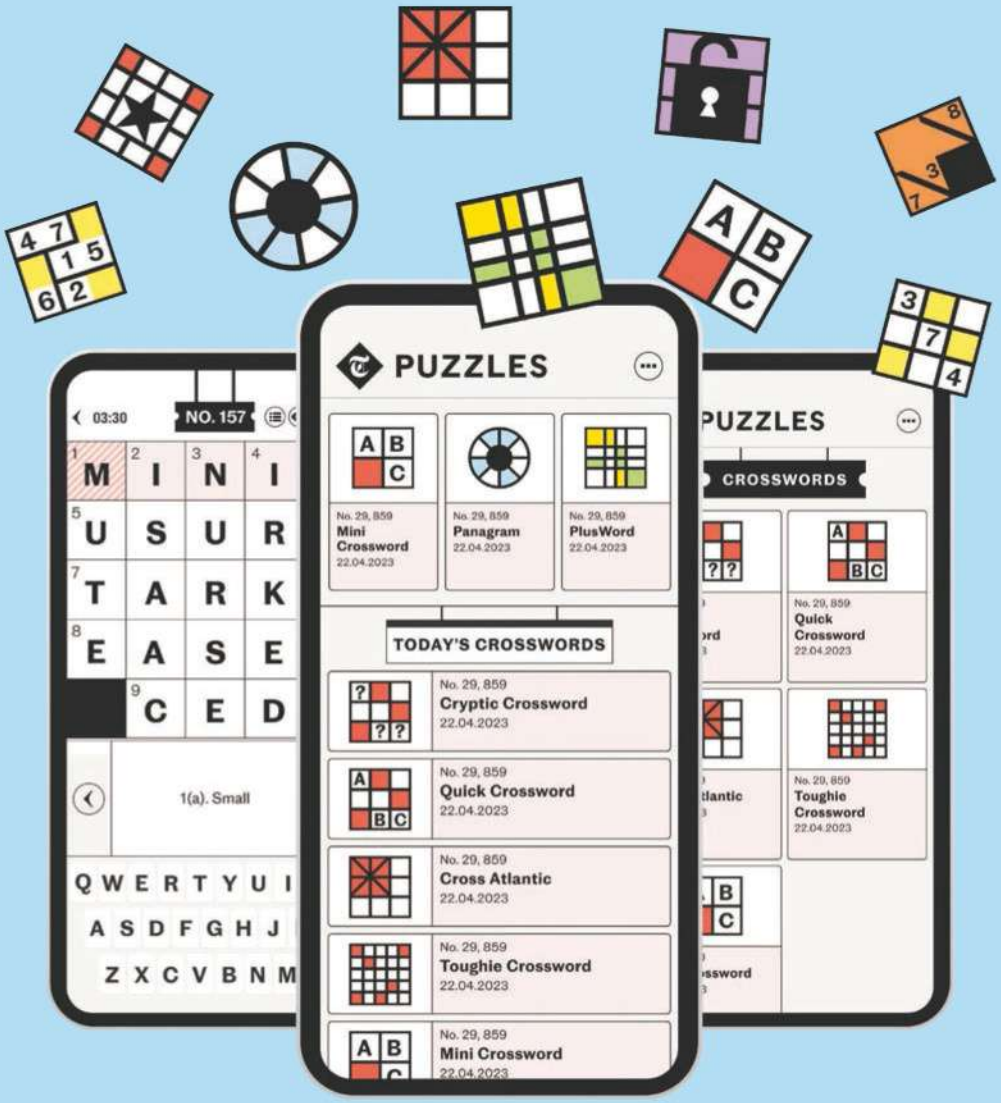

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Mission 2027

Racecar *meets the FIA's technical and safety chief to find out more about fundamental changes to the future of the World Rally Championship*

By DANIEL LLOYD

Motorsport is currently enjoying something of a boom in manufacturer involvement. Following technical regulation changes, road car companies have seen value in what racing at the highest levels can bring to their marketing. Having been on its knees five years ago, the FIA World Endurance Championship now has eight manufacturers in Hypercar, with more waiting in the wings. Formula 1's new rules for 2026 have tempted Audi and Cadillac to join as teams, and Ford as a partner to Red Bull's power unit company. The FIA Formula E World Championship continues to serve the electric sphere well with seven OEMs on board, five of which have already signed up for the next Gen 4 era.

It's not just circuit racing either. The FIA World Rally-Raid Championship, whose season kicks off with the Dakar Rally, has recently embraced the arrivals of Ford, Dacia and, from next year, Jaguar Land Rover with its Defender brand.

However, there is one major series that stands out as not having enjoyed the same kind of uptick. The FIA World Rally Championship (WRC) has been stuck on three manufacturers since Citroën's exit at the end of 2019. Toyota, Hyundai and Ford have produced some exciting competition, yet how stable is the current entry in the long term? Ford's programme is driven by the independent M-Sport squad, while Hyundai's long-term commitment is at present unclear as it puts more resource on its new Genesis sportscar for 2026.

It seems strange that the WRC has not been swept up in the trend of greater OEM interaction. It almost feels a bit unjust because stage rallying is still such a raw type of motorsport, held in stunning locations, that exposes driver skill like no other. It is no less appreciated on the ground either. Fans haven't stopped flocking to the hillsides around Monte Carlo, or into the forests of northern Europe. WRC Promoter, the company that runs the championship's commercial side, recently declared that the 2024 season attracted over a billion television views (however that is measured) and social media impressions. Yet manufacturers continue to look elsewhere, and grid numbers in the top class remain low. Something clearly doesn't add up.

The upcoming regulations focus on giving constructors a greater choice in bodywork design around a common safety cell, and the potential for different powertrain types in the future

FIA

The working title for the top class in two years' time is 'WRC 2027' rather than Rally1, a name which is looking increasingly likely to disappear after being around for just five seasons

Flexible future

This is why the FIA, which oversees the championship's technical regulations, is tweaking the blueprint for WRC cars in 2027. The global motorsport federation wants to make top-level rallying attractive to more competitors by being more flexible with its technical direction and pushing for cost reduction. It teased its intentions last summer (though similar ideas had been floated a few months prior) and unveiled its plans in December, following FIA World Motor Sport Council approval. Touted as giving the WRC a 'dynamic, flexible future', the upcoming regulations focus on providing constructors with a greater choice in bodywork design around a common safety cell, and the potential for different powertrain types to be used in the future.

'This regulation is designed with a clear target: to increase the number of cars in the top category,' says Xavier Mestelan-Pinon, chief technical and safety officer at the FIA. 'Currently, you have just 10 cars. We want to have 20-25 cars.'

Doubling the number of entries that can win a rally overall will require the top class in 2027 to be more accommodating, and slower, than Rally1 currently is. The WRC's top formula was introduced in 2022 after a quarter century of evolution under the World Rally Car rule set. Rally1 cars were developed to run with hybrid powertrains that produced more than 500bhp, making them some of the quickest ever to hit the WRC stages. However, despite having regulatory appendices allowing for conversion into non-hybrid specification for privateers, Rally1 has been pretty much off limits for independent teams, except for Cumbrian giant, M-Sport, with its Ford constructor programme. Consequently, it has remained limited in both entry numbers and diversity.

'Of course, the technical regulation is not the only one we need to improve to reach our target,' explains Mestelan-Pinon. 'Until now,

Rallying is still a hugely popular sport with spectators on stage and on TV, but the FIA wants more cars competing at the sharp end of WRC events

Jaanus Ree / Red Bull Content Pool

only OEMs are able to homologate cars; it is forbidden for others. In the future, it will be allowed for manufacturers and tuners with a shape coming from a road car, or a full prototype. This is completely new.'

Tuner boat

That use of the word 'tuner' is unusual in motorsport. While it conjures up images of low-slung, heavily modified road cars, it could be important for the WRC's future. A tuner in this context is defined as a racecar constructor that doesn't sell cars for the road. It could be a company like M-Sport, for example, if it developed its own WRC model, rather than the Ford Puma Rally1 it currently has. The FIA's stance is that if a tuner wants to enter WRC rallies with a complete prototype – maybe even something like the bizarre McRae R4 of the mid-2000s – it is welcome.

In fact, pretty much every body style you can think of will be permitted from 2027 onwards. The FIA wants to promote a wide range of vehicle looks, casting the net as wide as possible to attract manufacturers with different priorities. Sell an SUV? You can rally it. Family four-door saloon? Check. Humble hatchback? The rules will allow it, as long as it complies with the common safety structure beneath the skin.

'We want to keep it as open as possible, giving the automotive manufacturers the chance to come with whatever,' confirms Emilia Abel, FIA road sport director. 'And for the tuners, as we call them, to choose [whether they] work with the manufacturers.'

The safety cell that all cars in the WRC's top class will use from 2027 will be 'close' to that used in Rally1, according to Mestelan-Pinon. He predicts there will be 'small evolutions' but nothing drastic because the FIA has set an aggressive cost cap of €345,000 (approx. $360,000) per car. When a vision for the next set of regulations was first mooted in February 2024, a target of €400,000 was set for a similar package, so that's a big reduction. The current price is going to be hard for the current manufacturers to adjust to, considering it is roughly 50 per cent less than Rally1. Much of the savings will come from using engines and other internal parts with performance closer to today's Rally2, which produces just under 300bhp.

'It is the same tubular frame for the cockpit,' says Mestelan-Pinon. 'Front and rear it's open, and we will have double wishbones, which are completely new. For all the technical parts, it should mainly be [like the] Rally2 regulations for a more affordable car.

'Today, at the [FIA] technical and safety department, we are developing the safety cell for the cockpit. Each manufacturer will produce their part, based on our design.

Jaanus Ree / Red Bull Content Pool

The 2027 cars will be closer in performance to current Rally2 machinery, a necessary step to meet the aggressive cost target

We are doing studies and calculations to secure an efficient design, mainly for the safety. We have targeted the same results we have in Rally1. This is a high level of safety.'

Strut, you're stuffed

The switch from the traditional MacPherson strut design to double wishbone suspension is a notable change. Struts have been used in rallying for decades, offering enough spring travel for the rigours of the stages, whilst being relatively light and easy to package. Double wishbones, meanwhile, are more familiar in circuit racing. Combined with a vertical damper, they allow for more detailed control of the wheel's camber and caster angles. Manufacturers and tuners will be free to bring their own suspension components, this being a key area of performance and durability in rallying.

'We want to have a more efficient system than the MacPherson strut,' explains Mestelan-Pinon. 'You need to work on the friction in rally because of the suspension travel; it costs a fortune. On the double wishbone, friction is important, but much less than with the strut. You can have an efficient suspension, with a lot of travel, at lower cost.'

Torque meters are in vogue with the FIA at present, since their adoption in Formula E and WEC Hypercar. The devices keep track of car power outputs and are used to promote a level playing field. Torque meters were used at the Dakar Rally for the first time this year and were mentioned in the FIA's December announcement about the WRC 2027 rules. However, it isn't a done deal regarding their use in stage rallying. Mestelan-Pinon describes it as an 'open question' the FIA is trying to answer.

'Personally, I think it's a good thing for the future in rally,' he says, 'but never forget that, when speaking about rally, a car can compete in a world championship round but also in lower [national] championships. There, such devices are too complicated.

'We can address that. We can imagine having torque meters in the world championship and [turbo] boost ratios in national [rallying]. We are discussing that with our manufacturers.'

The FIA learned much about using torque sensors in off-road competition at the Dakar in January and Mestelan-Pinon is confident it will be easier to integrate them in stage rallying than cross country, due to lower inertia on the rear axle.

'All the teams were worried about that before the Dakar but, in the end, they were very happy and it worked well,' he says. 'We can fine tune the system, but it was a success. All the teams and manufacturers now understand they are not obliged to work on the engine, so it is very comfortable for them in terms of cost.

Lawrence Butcher

Cost reduction was a driving factor in the FIA mandating the use of double wishbone suspension instead of MacPherson struts (pictured)

'It doesn't work like in Formula E and WEC. It's not on the driveshaft, it's on the gearbox and, if we do it in rally, it's going to be the same. For cost efficiency, and also because in rally you have to change the driveshaft many times.'

Open minded

As with its approach to bodywork, the FIA is being deliberately open minded about powertrain technologies in rallying. Hybrids were introduced at the advent of Rally1, but ended up causing problems that outweighed their performance benefit. With the future rules, hybrids are back on the table, along with every other type of powertrain under the sun, including hydrogen and full electric. However, the WRC is likely to start with a focus on more traditional, non-hybrid, internal combustion engine vehicles, although it has drafted some designs for how the different powertrains would be integrated into the common safety cell.

'We know that, for example, with a full electric vehicle battery of 35kWh, we can have more or less the same power and weight as ICE,' says Mestelan-Pinon. 'For hydrogen, it's more challenging, especially for [fuel stored as] liquid, but it will not be very far away from the current specification in terms of power and weight.'

All-electric rally cars bring additional challenges in terms of charging, and Mestelan-Pinon suggests a 35kWh car would need to recharge every 40km or so. At a WRC event, competitors might do 50km of special stages alone, excluding liaisons, before reaching the service park. These stages are often in remote locations with no charging infrastructure, so the widespread adoption of EVs would likely require the current rally format to be adapted.

'The very first regulation is based only on ICE with sustainable fuel… [but] the cockpit is designed to accept EV, hybrid or hydrogen'

Xavier Mestelan-Pinon

'The very first regulation is based only on ICE with sustainable fuel,' confirms Mestelan-Pinon. 'In the future, the cockpit is designed to accept EV, hybrid or hydrogen. For the short term, though, we want to promote ICE.'

With internal combustion being favoured for now, more radical powertrain solutions are, realistically, being pushed towards the end of the decade. If having electric or hydrogen technology is a deal breaker for any manufacturer, it's hard to see them committing before then. Unless there would be a chance to showcase technologies non-competitively, like the innovative Garage 56 entry at the 24 Hours of Le Mans.

So, will the WRC's approach to the 2027 regulations tempt more manufacturers to join? It is hard to say right now, but the FIA hopes its promise of significantly cheaper, less complex cars will prove popular. The answer may lie in Rally2, which features production-based, four-cylinder, turbocharged cars that manufacturers build and sell to private teams. Last year, it averaged 28 entries per round in the FIA European Rally Championship and five manufacturers were represented. That's the sort of field the WRC wants at the sharp end of its rallies in two years' time.

'The ball is in the court of the manufacturers now,' declares Mestelan-Pinon. 'To design something that is simpler, they will not be able to use the same materials or architecture. In motorsport, we need to come back to something more affordable. If you launch a new regulation at a certain level of cost, year after year, it will inevitably increase. After 10 years, it [becomes] crazy.'

The Telegraph

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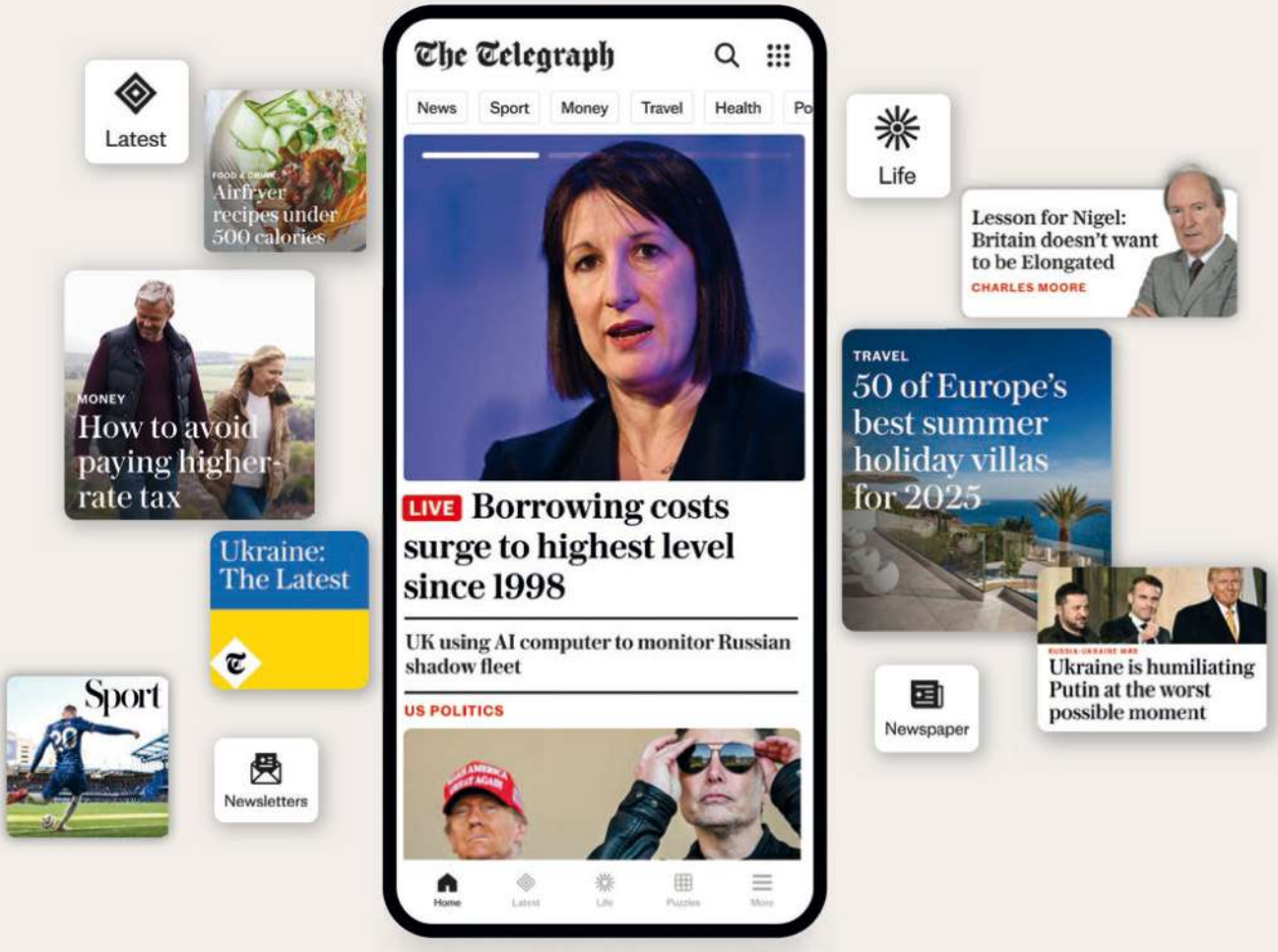

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The stability index

Dynamic racecar stability, the complete picture

By DANNY NOWLAN

One of the things I think we in automotive have made a complete mess of is quantifying racecar stability. Terms like understeer and oversteer are thrown around like a frisbee, but do people really understand what they mean? If you tune into F1 radio transmissions, you'll hear more complex phrases such as 'balance on turn-in isn't good.' What you hear precious little of, however, is explanation of how to quantify these terms. This is what we'll be discussing in this article.

The backbone of all this is the stability index. I've covered this before on multiple occasions, but it won't hurt to briefly review it again here. What the stability index measures is the moment arm of the centre of the lateral forces to the c of g. To make it a bit easier to understand, this is non-dimensionalised by wheelbase. What we are measuring is illustrated in **figure 1**.

Mathematically speaking, it looks like the formula shown in **equation 1**.

$$C_f = \frac{\partial C_f}{\partial \alpha_f}\Big|_{\alpha=\alpha_f} \cdot (F_{m1} + F_{m2})$$

$$C_r = \frac{\partial C_r}{\partial \alpha_r}\Big|_{\alpha=\alpha_r} \cdot (F_{m3} + F_{m4})$$

$$C_T = C_f + C_r \qquad (1)$$

$$stbi \approx \frac{a \cdot C_f - b \cdot C_r}{C_T \cdot wb} - \frac{a^2 \cdot C_f + b^2 \cdot C_r}{V_x \cdot C_T \cdot wb}$$

Where,

$dCF/da(\alpha_f)$ = slope of normalised slip angle function for the front tyre

$dCR/da(\alpha_r)$ = slope of normalised slip angle function for the rear tyre

$Fm(L_1)$ = traction circle radius for the left front (N)

$Fm(L_2)$ = traction circle radius for the right front (N)

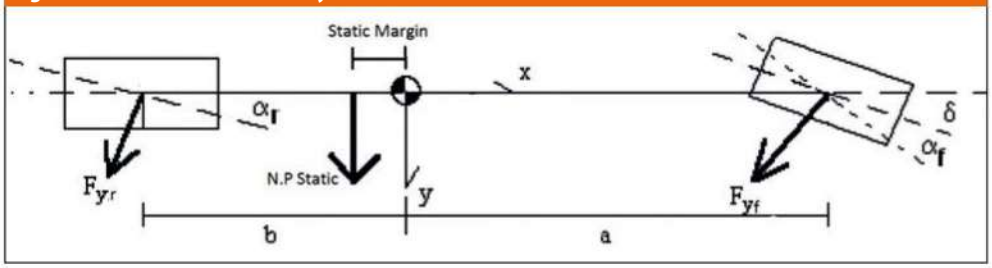
$Fm(L_3)$ = traction circle radius for the left rear (N)

$Fm(L_4)$ = traction circle radius for the right rear (N)

To give you a better feel of the normalised slip angle gradients, **table 1** from the default ChassisSim slip curve will help show the way.

A question I am often asked is what happens when we hit the peak slip angles? In this case, the stability index calculation becomes a limit calculation. However, as a rough rule of thumb, if you clip this at 95 per cent of the peak slip angle, this will be quite sufficient to get you started.

Fig 1: Illustration of the stability index



The next key thing to review is what the stability index result means. If the stability index is less than zero, then the centre of the lateral forces is behind the c of g and, for a given response, the car will be stable. When the stability index goes positive, that indicates the centre of the lateral forces is in front of the c of g. So, when a car is subject to a disturbance in this condition, unless the driver actually does something to prevent it, the vehicle will be out of control.

Metric equivalents

Before we go deeper into this, we need to talk about stability index vs other metrics. The reason for this is that understeer, oversteer and balance are all manifestations of what we see in the stability index.

For example, you might hear a driver say they are experiencing terrible mid-corner understeer. What is happening here is that in the mid-corner condition, the car's stability index is moving rearwards. In most cases, this will be due to the outside front tyre experiencing load saturation, combined with more load placed on the rear. Conversely, if a driver says they are struggling with turn-in balance, the stability index has moved forward to a point where their reactions can't keep up.

Table 1: Plot of normalised ChassisSim slip angle derivatives

Slip angle (deg)	Slip angle (rad)	F_{NORM}	δC/dα
0	0	0	14.323
1	0.0175	0.25	13.925
2	0.0349	0.5	12.731
3	0.0524	0.69	10.742
4	0.0698	0.85	7.9567
5	0.0872	0.96	4.375
6	0.1047	1	0

What the stability index measures is the moment arm of the centre of the lateral forces to the c of g

Now, before we talk about the evaluation of the stability index from turn-in to mid-corner, here are some really good rules of thumb for what to look for down the straight. The results shown in **table 2** have been cross referenced by comparing the ChassisSim lap time simulation vs Driver-in-the-Loop vs actual data for a rear-wheel drive racecar.

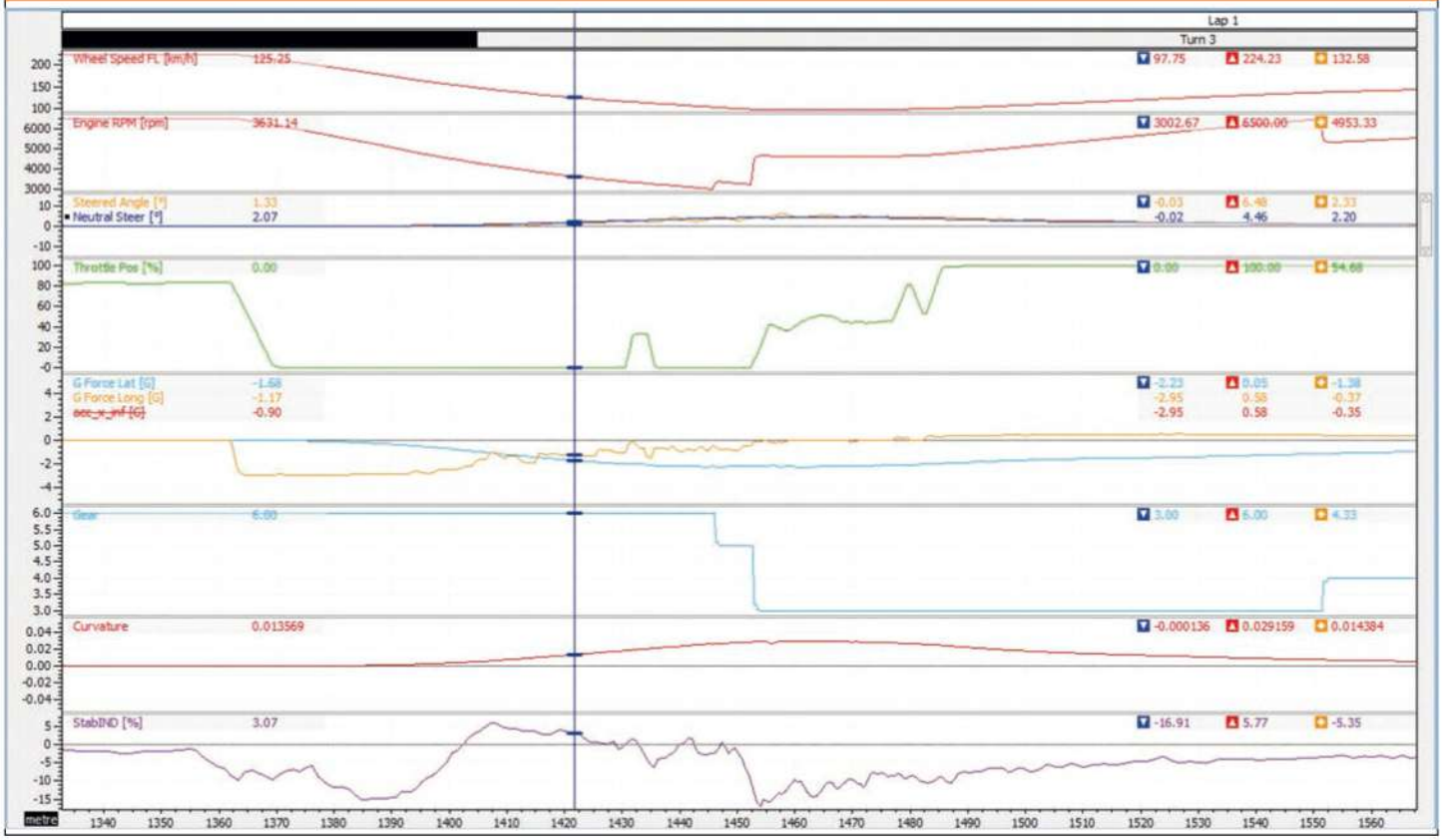
The reason the stability index becomes more negative as the power increases is to provide a buffer, so that when full power is applied, you have some residual stability to lean on. I've used these rules of thumb on some extreme racecar design projects and they have proved very effective.

With the rules of thumb out of the way, let's talk about the evolution of racecar stability in a corner. This is illustrated in **figure 2**. The last plot is stability index, and this is from a lap time simulation in ChassisSim. Under initial braking from the 1360-1400m mark, the stability index is nicely behaved at -10 to -15 per cent. This reflects the fact the car is under hard braking and the bulk of the front tyre forces are being used to stop it.

Table 2: Rough rules of thumb for stability index at end-of-straight conditions

	Eng power ~ 170 kW	Eng power ~400 kW	Eng power ~600 kW
Superstar	-3 to -4%	-5 to -7%	-8 to 10%
Average	-6 to -8%	-10 to -12%	-12 to 14%
Bad driver	-12 %	-16%	-20%

Fig 2: Evolution of racecar stability in a corner



From the 1450-1470m mark, the stability index drops as low as -16 per cent. This reflects the car being under a balanced throttle with the frontal load transfer at its maximum.

Where things get interesting, however, is between 1400-1500m. In this range, the stability index initially climbs to 5.73 per cent but ends up at -6 per cent. This trend indicates the car would be a handful during turn-in under mixed conditions.

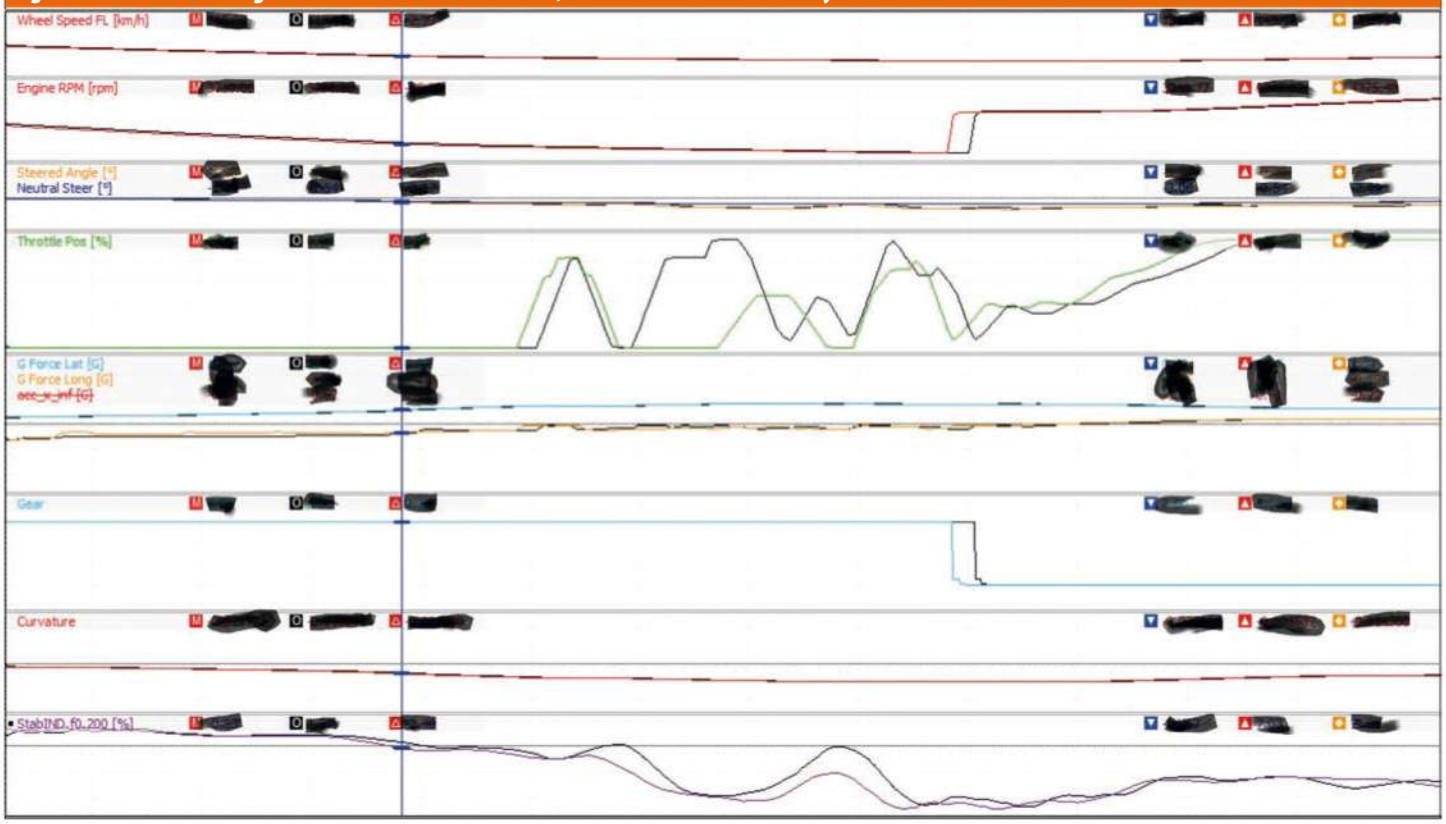
If we go to the third trace, which is the steer and neutral steer plot, you can see the steer going up and under the neutral steer plot, which confirms the driver has to be on top of their game to drive this car.

Turn-in evaluation

A follow on from this is one of the most challenging exercises in race engineering: evaluating what a car is doing at turn-in.

Some customer work I did last year was most enlightening in this regard, and the results are shown in **figure 3** (as this is actual data, scalings and numbers have been redacted). The coloured plot is the baseline and the black plot is the second configuration, but the important thing to note is the similarity to **figure 2**. I'll direct your attention to the last plot, which is stability index. As can be seen from the purple-coloured plot, apart

Fig 3: Two different configurations of a customer racecar, and their effect on stability



from the very initial turn-in, the line is mostly below zero and the driver in question had no problem handling that.

The black plot, however, is the second configuration. Not only does that one stray into positive stability index, it is very close to zero per cent on at least two occasions. In that configuration, the driver couldn't tolerate driving the car, making it an excellent case study for how simulation can be used to identify instability at turn-in.

Quick analysis

One further thing that should be addressed here is why not just use the comparison between actual and neutral steer to evaluate car stability? Indeed, that very question was a centrepiece of my first ever article on racecar stability. As methodologies go, it's a simple one, and one I use heavily in my data work because it's a good 'canary in the coal mine' analysis tool that is quick and easy.

However, it falls down in two areas. Firstly, it works really well when you are looking at sim data, or when you have a Max Verstappen, Lewis Hamilton or Fernando Alonso behind the wheel. Once you stray from this pinnacle of talent, though, drivers will inevitably add in too much steering lock. So, while it's a great tool to use, it's not bulletproof.

Secondly, when it comes to driveability, changes will show up more on the stability index than they will in steering wheel angle. To further explain this, look at **figure 4**, which shows the effects of moving the forward aero balance by five per cent on a Formula 3 car.

Again, this data is taken from a lap time simulation, but compare the third trace, which is steering, and the last trace, stability index.

The stability index can explain a lot of driver complaints, such as struggling with poor balance on turn-in and mid-corner understeer

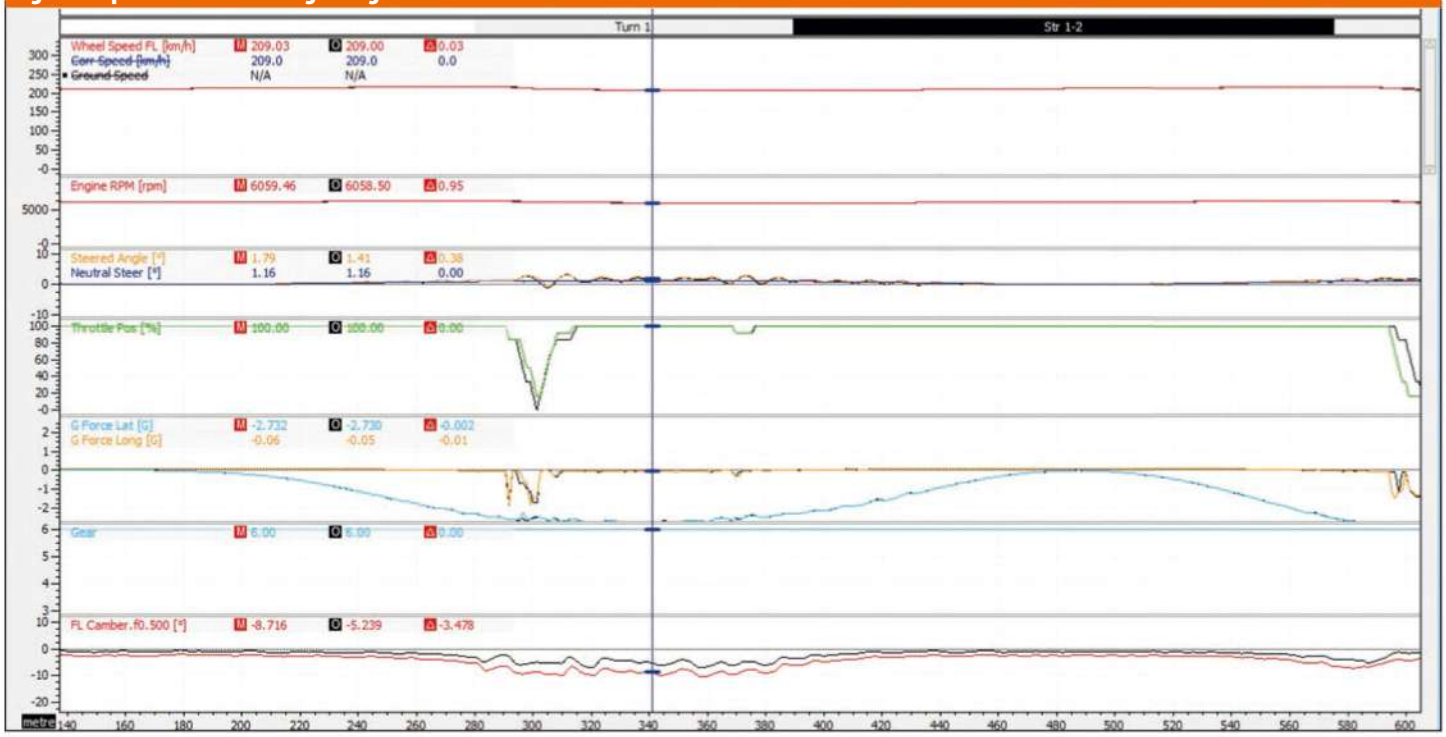
In this plot, the coloured trace is the baseline, and black is with the aero balance moved five per cent forward. The difference in the steer trace is negligible, but you'll note there is a three per cent change in the stability index. This confirms that stability index gives you a much better calibration of handling changes than steer alone.

Cross reference

Finally, to wrap things up, a further very effective tool is to cross reference the stability index simulation plots against what the driver of the car is saying. As you start making changes to address turn-in stability, it will act as a key analysis tool to see what the person behind the wheel can tolerate.

In closing, the stability index is a very powerful tool in quantifying racecar stability. As we have seen from the examples here, it will vary in braking, turn-in and mid-corner, and the scale of those variations reveals a great deal about what the car is doing. It also gives a more precise reading on what a handling change actually does, both to the car and for the driver. Use this as part of your simulation analysis and you will have a great insight into the right way to solve a handling issue. Cross reference your findings with driver feedback and you'll be winning.

Fig 4: Comparison of front wing change on a Formula 3 car



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SEWAGE POWER

IN BRIEF

Tim Cindric has stepped back from his position as overall day-to-day leader of Team Penske's racing programmes. Cindric will remain president of the outfit's IndyCar activities, with **Ron Ruzewski** continuing as managing director. **Michael Nelson** (leading NASCAR), and **Jonathan Diuguid** (LMDh) will report directly to Roger Penske.

Red Bull has signed a multi-year renewal with **Hexagon** to continue using the Swedish company's digital reality technologies in F1. Hexagon provides Red Bull with 3D laser scanning services and has worked with the team since its early days.

After an initial trial, the **Racing Bulls** F1 team has signed a three-year deal to continue using Roboze's 3D printing and materials analysis tools.

Leonardo Galante has left Lamborghini after more than 16 years to take up the role of chief technical officer at Tatuus. Galante was an aero and chassis engineer for Ferrari before moving to its rival Italian sportscar manufacturer, where he was in charge of technical responsibilities in the company's motorsport activities. Most recently, he worked on the SC63 LMDh car and the development of the Temerario GT3, which will be launched later this year.

BMW M Motorsport has partnered with simulation company **AccuSim**, using the Trident Genesis Motion Platform to help its LMDh and GT programmes. The platform offers six degrees of freedom, promising ultra-low latency and a compact design that will slot into BMW's car architecture.

Peugeot Sport has renewed its partnership with AI firm **Capgemini**, based around the 9X8 LMH. The companies have collaborated on developing a data analysis platform, whose AI model powers virtual sensors embedded in the 9X8's onboard computer to aid decision making on car settings and to facilitate real-time adjustment. Capgemini claims Peugeot's Hypercar race engineers have streamlined their data analysis tasks from days to minutes.

Tatuus teases new Formula Regional car

FRMEC

FIA Formula Regional is a step between Formulas 3 and 4. The second-gen Tatuus is set to debut early next year in Formula Regional Middle East

Tatuus is planning to introduce a second-generation Formula Regional chassis next year. The Tatuus T-326 is set to replace the T-318, which has been active in various junior series around the world since 2018.

The new car will be powered by a 1.6-litre, three-cylinder Toyota engine developed by Autotecnica Motori in Italy. It will produce 270bhp and up to 360Nm of torque.

According to Tatuus, the T-326 represents a 'natural evolution' of its predecessor and aims to 'improve and refine the driving experience.'

The aerodynamics package has been updated with a profile aimed at reducing wake to make it easier for cars to follow each other. The car has also been made lighter and comes with revised suspension and steering systems.

Its usage next year, and final technical figures, are subject to FIA homologation, although the Formula Regional Middle East series has already committed to using it; the FRMEC calendar typically runs early in the year as preparation for the European championship.

Since its establishment in 2018, Formula Regional has grown into six FIA-approved regional series. The T-318 was also previously used in the defunct W Series and made its Macau Grand Prix debut last year.

Different companies can build Formula Regional chassis, and Tatuus is not the only one readying a new car. Ligier Automotive is planning to unveil its new JS F326 later this year, after it emerged that its parent company had recently purchased a majority stake in fellow French constructor, Mygale.

Pirelli plotting new ultra-soft tyre debut

Formula 1 supplier, Pirelli, is planning to introduce its new, ultra-soft C6 tyre compound to the Emilia Romagna Grand Prix at Imola in May.

The Italian supplier developed this latest option primarily for street circuits, due to the less aggressive asphalt putting less energy through the tyres. However, Pirelli's motorsport director, Mario Isola, told reporters at pre-season testing last week that the C6 would likely make its debut at a permanent track.

'I believe we are going to confirm the C6 for Imola and probably Montreal,' he said. 'Depending on the results we have from [those] two representative circuits, we can decide to use the C6 also in Singapore and Vegas. If we confirm this, plus Monaco, it is five races, which is enough for the C6. We don't need to use it for 20 races.'

F1 cars have struggled for grip on the low-aggression Imola track surface in the past, so Pirelli is looking to engage is ultra-soft tyre to help with that. Imola also has a long pit lane delta of almost 30 seconds.

'It's an age,' added Isola. 'If we have a more aggressive selection with C4, C5 and C6, looking at our simulations that are not perfect, but not too far from reality, we believe that two stops in Imola are more possible.'

Pirelli updated all of its F1 tyre compounds for 2025 to give them stronger mechanical resistance in a bid to reduce graining.

Electric NASCARs assemble

The first two NASCAR electric prototypes have been revealed, following on from the series' own CUV-shaped demonstrator in 2024.

Ford revealed its new Mustang-Mach E demonstrator at the end of January, while Chevrolet introduced its Blazer EV.R in February. Both vehicles are intended to showcase their respective company's electric technology as NASCAR continues to explore greener options.

'While we will continue to race our proven and winning V8 technology in NASCAR for years to come, we continually look for ways to improve the combination of power, durability and efficiency to transfer learnings from racetrack to the showroom,' says Eric Warren, executive director, global motorsports competition at General Motors, 'especially as we bolster Chevy's consumer EV line up.'

GM's prototype Blazer is built on the NASCAR Gen 7 platform and is four-wheel drive. It delivers more than 1300bhp from three six-phase electric motors that rev to 15,000rpm, with energy stored in a 78kWh liquid-cooled battery.

The Mustang has a full carbon fibre tub and joins Ford's other recent EV demonstrators, including the F-150 Lightning SuperTruck and the Super Cobra Jet 1800.

Ford's Mustang-Mach E NASCAR prototype is built around a full carbon tub and uses existing Cup Series suspension, brakes, steering and wheels

GM's new Chevy Blazer EV.R sits on a regular Gen 7 chassis but with triple electric motors and a 78kWh liquid-cooled battery in place of the traditional V8

Porsche leads push to revise prototype regulations for Le Mans 2030

Porsche is behind a move to create an alternative set of regulations, formulated by the manufacturers currently competing in Hypercar, to be introduced in 2030.

The ACO and FIA will release a set of LMH regulations that will allow hydrogen powertrains to compete for overall victory in the WEC and at Le Mans, but Porsche's head of motorsport, Thomas Laudenbach, feels there should be an alternative, based on the needs of those already competing.

'We all should have an interest in having a very healthy and stable platform,' says Laudenbach. 'I'm not saying we carry over LMDh rules for everybody, I'm saying let's put these two set rules side by side and let's talk to the manufacturers about what is important for [each of them].'

There are currently eight manufacturers racing in the WEC, with Acura also competing in the US. Genesis, Ford and McLaren are coming, and Laudenbach wants to ensure the new rules suit them all.

'The worst, and most stupid thing we can do is to sit back,' says the German. 'It's time to think about what can we do to keep [the class] stable and healthy.'

IN BRIEF

Prema Racing has entered an agreement with **Halo by Orthene** that will take effect from the start of the 2025 season. Each of the Italian team's cars, from Formula 4 through t o IndyCar, will use Halo P1 brake fluid. The deal is for three years.

Swiss safety fence manufacturer, **Geobrugg**, has had its 6m high fencing approved by the FIA for use at high-speed corners, steep elevations and grandstands where spectators might be exposed to flying debris. Racetrack fencing is normally 3.5m high, but some venues, including Monza, exceed that. Geobrugg's product is the first to be homologated for use on FIA grade 1 and 2 circuits.

McLaren has extended the contract of its F1 technical director of aerodynamics. **Peter Prodromou** was appointed to the role in 2023 and has agreed to stay on a 'multi-year' deal. He started with McLaren in 1991, and then moved to Red Bull before returning to the Woking team in 2014.

Former Ferrari F1 race engineer, **David Greenwood**, is back in the championship as Alpine's racing director. He joins the Enstone outfit after a three-year stint with Hitech GP, the junior single seater outfit established by current Alpine team principal, Oliver Oakes.

Cars at the **Monaco Grand Prix** will be required to make two pit stops, regardless of conditions, in a bid to improve the 'sporting spectacle', according to the FIA. Three sets of tyres will be mandated for F1's famous street race, and two different compounds must be used if the weather is dry.

ABB will continue as the electric charger provider for the FIA Formula E World Championship into the Gen 4 era, which begins next year. It means the Swiss company will hold the post until the end of the 2029-'30 season.

Aston Martin will feature in the DTM for the first time since 2019, courtesy of last year's 24 Hours of Spa winner, Comtoyou Racing, which has committed with a pair of Vantage GT3 EVOs.

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PIT CREW

Editor
Andrew Cotton @RacecarEd
Email andrew.cotton@chelseamagazines.com

Deputy editor
Daniel Lloyd @RacecarEngineer
Email daniel.lloyd@chelseamagazines.com

Sub editor
Mike Pye

Art editor
Barbara Stanley

Technical consultant
Peter Wright

Contributors
Mike Breslin, Lawrence Butcher, Jahee Campbell-Brennan, Dejan Ninic, Danny Nowlan, Bozi Tatarevic

Photography
James Moy

Acting Director of Commercial Revenue
Simon Temlett

Advertising manager Doug Howard
Tel +44 (0) 20 7349 3796; +44 (0) 7743 192 575
Email doug.howard@chelseamagazines.com

Marketing executive Loulou Easton
Email loulou.easton@chelseamagazines.com

Publisher Greg Witham
Managing director Marie Davies

Editorial and advertising
Racecar Engineering, Chelsea Magazine Company, 111 Buckingham Palace Road, London, SW1 0DT **Tel** +44 (0) 20 7349 3700

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Funding gap

The system needs to change, but who will pay to change the system?

The topic of money is never far from the heart of racing. Privateer teams seek it through sponsorship or individual investment; manufacturers are looking for it from either their R&D departments or from boardroom sign-off, which requires buy-in to the advantages of racing. In the meantime, the rules of engagement on track remain the same as they ever were: how fast can you afford to go?

In a recent interview with German publication, *Auto Motor und Sport*, Adrian Newey pointed out the talent drain in Formula 1 due in part to cost-cap regulations, which see competitors' budgets strictly limited. Newey suggested teams were losing engineers to other series, including sportscars and Formula E, that do not operate under the same restrictions. Worse, young engineers are transferring into industry, which happily takes their hard-earned expertise and pays handsomely for it.

On track, as more international series move to hybrid, the need for engineers who are able to work with the technology increases. However, the number of such engineers is reaching a critical point, and they are becoming highly sought-after. Technology development is primarily focused on battery technology, vehicle control and efficiency for competition purposes rather than production car development.

Team owners and suppliers are saying, 'it ain't broke, don't fix it', yet it does *need* to be fixed

Wage war

F1 teams have to go even further in 2026, and will have to pay good wages to retain engineering talent as other series and industry offer more. This extends beyond wages, though. It also affects hardware, and suppliers. Looking at the next generation of LMP2 cars for 2028, it's hard to see how anything could improve on the ORECA chassis that has been the product of choice for several years. The car is safe, fast and reliable, and teams know how to get the most out of it. Most own enough spares that racing is now relatively inexpensive, and it's possible to contest series around the world – in the US, Europe and Asia – with the same cars, so what needs to change?

The same is happening in IndyCar. The US series has a chassis that was introduced in 2012 and remains safe, fast and reliable. But the fact the chassis is now eligible for historic racing is just one indicator that something needs to change. LMP2 will soon be in the same boat, and its credibility will be similarly hurt.

Admittedly, IndyCar and LMP2 have slightly different issues. The former has a sole chassis supplier, so any change is going to be irrelevant in terms of the competition. Drivers have called for lighter IndyCars, but the series is looking for something exciting in terms of design. Team owners, on the other hand, are looking at their budgets and thinking, 'if it ain't broke, don't fix it'.

In LMP2, four chassis suppliers are eligible to build cars. Ligier, Dallara and Multimatic can, and have, but they were not as competitive, so never sold in the same volume as the ORECA 07. They are looking for a change to the regulations to give them a new way in. However, with so many teams firmly established with ORECA, it's hard to see why the rule makers would budge. They might, but which of these companies will stomach the cost of building a car to a cost cap formula? That is why it emerged at Le Mans last year that a spec chassis LMP2 category is on the cards.

It's the same situation with engines. Will Gibson, the sole supplier to LMP2, really create the 'modern racing engine' the ACO and FIA have asked for, and then lease it under a cost-controlled regulation? Again, team owners and suppliers are saying, 'it ain't broke, so don't fix it'. Yet it does *need* to be fixed. The question is, who will foot the bill? Will it be the suppliers, who will never recoup their development costs, or the teams, who don't want to invest any more?

This is where the FIA should be focusing its efforts, by looking at how to keep racing sustainable into the future. Long homologation periods simply lead to stagnation. Cost capping gives other teams, and industry, the opportunity to poach talent, yet without a cost cap teams can't afford to race. The system is under intense pressure, and that pressure needs to be relieved.

Time to re-think

Perhaps now is the time to remember our late columnist and legendary engineer Ricardo Divila, who once made the point that racing today costs the same as it did in the 1970s; it costs everything you have.

It is time to re-think racing on a global level by putting it back into the hands of privateers, reducing the cost of competing and allowing teams to make enough money to keep the lights on. It worked for nearly a century in all classes up to, and including, F1. Maybe now is the right moment to step back in order to secure our sport's future.

ANDREW COTTON Editor

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